THE LATE QUATERNARY ENVIRONMENTAL HISTORY OF FIJI

By

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DECLARATION

Except where otherwise indicated
this thesis is my own work.

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November 1986

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My main pollen site has a name, Tagimaucia, which roughly translates from the Fijian as "tears of despair". Fortunately, my field assistants, family and friends proved to me that you can keep smiling, even whistling, when it hasn't stopped raining for days, when you are up to your thighs in mud, cold, and on the odd occasion lost, and when the computer, or something in the lab, with my assistance, has yet again done a bunk. Thanks.

ABSTRACT

This thesis reports the results of analyses of vegetation history in the Fiji Islands. Selected sites have been pollen analysed, and their results used to provide a record of vegetation change that contrasts with analogous records from the Australasian region. Records from two of the sites (Lake Tagimaucia and Wainisavulevu Creek) extend into the Pleistocene, the former providing a continuous vegetation record from 14 300 BP to the present. The remaining sites (Nadrau Swamp, Bonatoa Bog, Raralevu, Vunimoli Swamp and Melimeli Swamp) originated in the mid- to late Holocene.

At 23 000 BP and from 13 000 to 9000 BP the vegetation of windward Fiji suggests that rainfall was at least 50% lower than present and was more seasonally distributed. Temperatures were probably at least 2°C below present. At 14 300 to 13 000 BP the vegetation suggests that temperatures were possibly 4°C below present. It is postulated that such changes were brought about by a substantial reduction in regional sea surface temperatures and less persistent south-east trade winds.

After 13 000 BP the vegetation near Lake Tagimaucia gradually approached its present composition, although this was not achieved until about 6300 BP. The initial vegetation changes suggest climatic amelioration. Present sea surface temperatures were probably reached by 9000 BP. The delay in synthesis of the vegetation may reflect sustained tectonic activity in the area.

From 6300 BP to the present the pollen assemblages from the Fijian sites suggest little or no significant climatic variation. The vegetation changes which are recorded are related to authochthonous developments at the sites, tectonic and volcanic activity and anthropogenic disturbance.

The pollen and carbonised particle records from the Rewa and Navua Delta sites, in south-eastern Viti Levu, and Nadrau Swamp, in central Viti Levu, clearly demonstrate the impact of humans on the Fijian environment. At the coast, burning is evident from 4300 BP and the forest vegetation is replaced by secondary forest and grassland at 3000 BP. A mosaic of forest and grassland is indicated from then until the present suggesting shifting patterns of activity in the delta regions. Intensification of agricultural activity at the coast is indicated from 1500 BP. There is no evidence from these sites that sea level has been significantly different from its present level since 4300 BP.

Evidence from Nadrau Swamp indicates a phase of clearing and burning inland sometime before 2000 BP and a subsequent reduction in human activity from about 1000 BP. This shift in population may correspond with the period of agricultural intensification at the coast. This pattern is repeated on many other islands in the south-west Pacific.

A comparison of the Fijian data with other records from Australasia indicates there may have been a zone of aridity at latitudes around 17°S during the last glacial period, perhaps related to lower sea surface temperatures and less persistent south-east trade winds. Post-glacial climatic amelioration apparently progressed steadily in Fiji while elsewhere in the region an early to mid-Holocene climatic optimum is recorded. It is possible that minor climatic changes in the Holocene did not elicit a vegetation response in the equable climates of windward Fiji.

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CHAPTER 1

LATE QUATERNARY ENVIRONMENTAL CHANGE IN AUSTRALASIA

1.1 Introduction

Long and detailed palynological records from montane New Guinea (Hope 1976; Walker and Flenley 1979), north-eastern Australia (Kershaw 1976), south-eastern Australia (Singh and Geissler 1985; Colhoun *et al.* 1982), and New Zealand (McGlone 1985) have shown that widespread vegetation changes have occurred in both tropical and temperate Australasia during the late Quaternary period. Interpretation of these vegetation changes has been largely in terms of climatic variation, which is shown to be broadly synchronous across the region. A review of the available palaeoenvironmental syntheses for any one area, however, shows that there are many other factors which make separation of the climatic element difficult.

Factors which must be considered include the presence of humans for at least 40 000 years in Australia (Tindale 1981) and 26 000 years in New Guinea (Bulmer 1982). Some vegetation changes in these areas have been tentatively attributed to anthropogenic disturbance (Singh *et al.* 1981; Powell 1982). It is clear that widespread and intensive human activity is indicated in many Holocene vegetation and geomorphological records.

The interpretation of vegetation change is also complicated by the independent behaviour of plant taxa in the face of environmental change. This is especially so in areas where biogeographic barriers exist (or have existed in the past) to isolate certain vegetation habitats. In these situations the component taxa must develop strategies to deal with environmental change which takes them beyond their normal tolerance levels or they become extinct, either locally or totally so. Hope (1986) suggests that one of the strategies may be for the component taxa of certain communities under threat by environmental change to survive in subordinate niches in other communities and then expand and re-form as a community when an appropriate niche again becomes available. This is possibly the situation which prevailed as the subalpine forests of New Guinea formed during the early post-glacial period (Walker and Hope 1982; Hope 1986). Consistent patterns of vegetation change across an area, even with comparable floras and experiencing similar climatic change, may therefore not be apparent.

Further complications arise because the effects of climatic change may be compounded by the effects of sea level change. At the last glacial maximum, wide expanses of continental shelf were exposed, modifying local climates. North-eastern Australia and New Guinea especially experienced more continental environmental conditions as the Barrier Reef Province, Gulf of Carpentaria and Arafura Sea were exposed as dryland. As sea level rose, local rainfall patterns were probably affected more by the presence of shallow, warm water on the continental shelf than by regional precipitation increases.

It would be desirable then, for the sake of understanding late Quaternary climatic patterns in Australasia, to examine an area where environmental change is likely to be relatively free of the above factors. Island ecosytems have considerable potential for testing many biogeographic problems, and given the complications in the Australasian region noted above, the islands of the south-west Pacific may be the most suitable area to look to extricate climatic change from the palaeoenvironmental record. Human populations have been present on these oceanic islands for only the past 4000 years or so at most (Jennings 1979; Spriggs 1985). This period has probably been one of minimal climatic change in Australasia (Bowler *et al.* 1976), so there is also the opportunity to examine human impact on pristine environments.

Environmental change during the last glacial/interglacial cycle may not have been severe in the south-west Pacific, so significant biogeographic barriers within any particular island group may not have formed. Distances on individual islands are not great, thus it may be possible to examine the behaviour of plant taxa in this situation to see whether local extinctions occur on this scale, and to compare this with records from more complex areas in the region. Further, while maximum sea level reduction had a profound effect upon the size and number of small, oceanic islands (McLean 1980), there is no question of any of these islands assuming continental proportions. A terrestrial record of environmental change from an essentially oceanic setting may contribute to the understanding of late Quaternary climatic patterns in Australasia. At present no long palynological records are available for the south-west Pacific, although long records exist for Easter Island in the central Pacific (Flenley and King 1984) and the Galapagos Islands in the eastern Pacific (Colinvaux 1972).

Permanent, natural lakes and swamps suitable for pollen analysis are rare on the islands of the south-west Pacific, and those which do exist are generally contained within volcanic craters close to sea level. Conditions are often brackish and sedimentation within them related in age to the arrival of the sea at its present level, some 6000 years ago. Examples of such sites include the lakes and swamps on Gaua in Vanuatu, Tikopia in the Solomon Islands, Aunu'u in American Samoa, and Niuafo'ou, Tofua and Late in Tonga (Maciolek and Yamada 1981; Southern *et al.* in press 1986). Reconnaissance showed that there are also suitable palynological sites on some islands of the Fiji Group which can provide a record of vegetation change in an oceanic island setting for comparison with the continental records from Australia, New Guinea and New Zealand.

This thesis presents a study of a range of palynological sites in the Fiji Group, selected for their potential to provide vegetation records which will allow closer definition of long-term vegetation changes and human impact on the environment. The coastal sites have also the potential to provide data on past sea levels.

1.2 The Fijian Palynological Sites

The Fiji Islands are located between 15° and 22°S and 177°W and 175°E, see Figure 1.1. The islands are oceanic and the main islands (Viti Levu, Vanua Levu, Taveuni, Kadavu and Ovalau)[1] are largely volcanic in origin, but many of the 500 or so smaller islands in the archipelago are formed as either low coral atolls or raised limestone blocks (Derrick 1965). The formation of the islands began at least by the early Oligocene (Rodda and Kroenke 1985) and it is likely that they remained submerged for much of that time (Green and Cullen 1973). The native flora of about 470 plant genera has many elements in common with the Malesian forests of south-east Asia and New Guinea, although there is a marked attenuation in species diversity (van Balgooy 1971).

The palynological sites identified for investigation in Fiji are briefly described here.

1. Lake Tagimaucia is a volcanic crater lake and swamp lying at 800 m altitude on the island of Taveuni. It has the potential to provide a lengthy record of vegetation change pre-dating the arrival of man.

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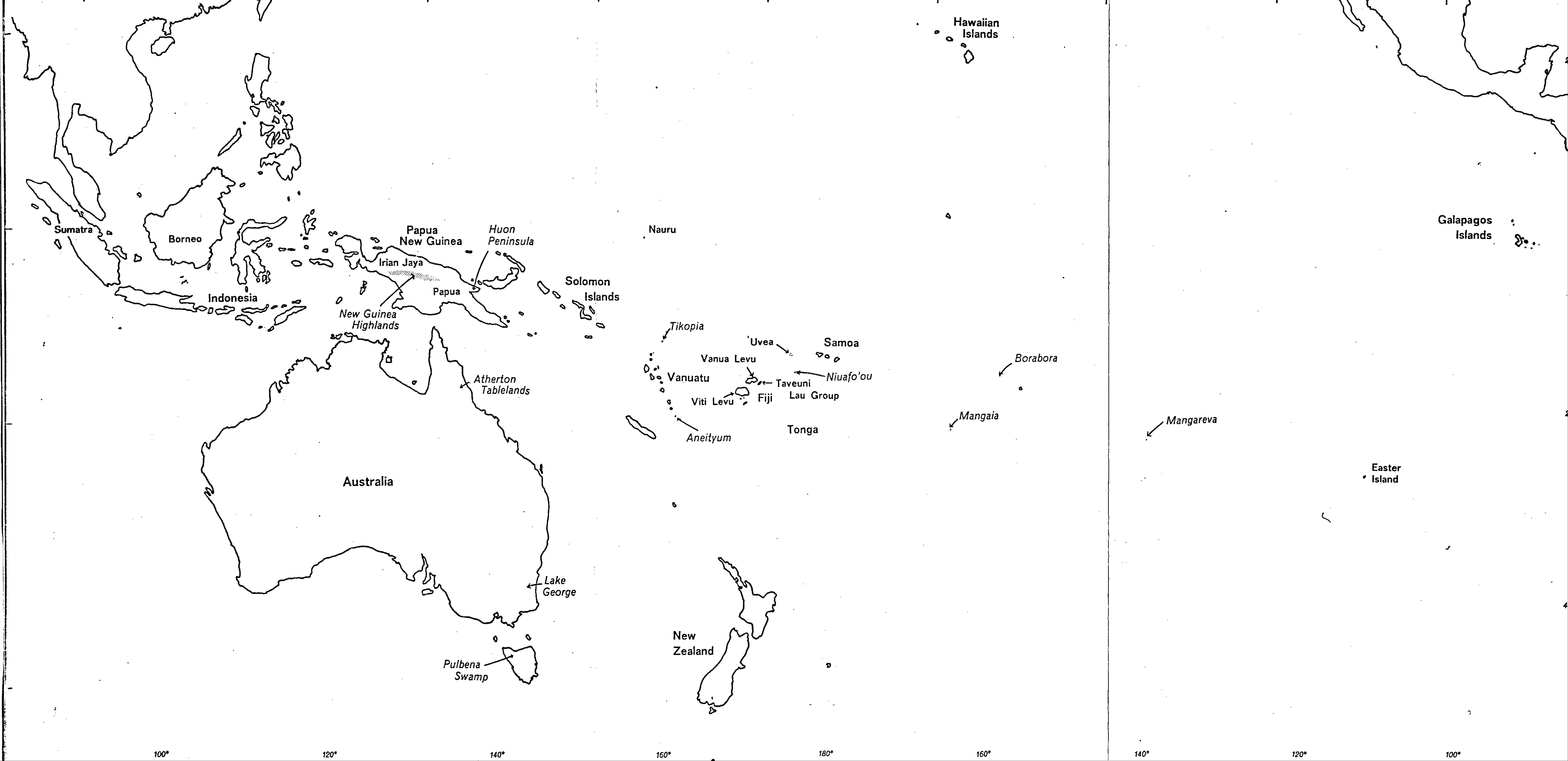
[1] Pronunciation of Fijian words uses the following conventions:

1. "g" pronounced "ng" as in sing
2. "b" pronounced "mb" as in member
3. "d" pronounced "nd" as in send
4. "c" pronounced "th" as in feather
5. "q" pronounced "ngg" as in finger.

Many early publications relating to Fiji spell Fijian words phonetically. All Fijian spelling in this thesis follows the conventions set out above.


Hawaiian Islands
Nauru
Sumatra
Borneo
Papua New Guinea
Irian Jaya
Papua
Huon Peninsula
Solomon Islands
Indonesia
New Guinea Highlands
Galapagos Islands
Tikopia
Uvea
Samoa
Vanua Levu
Vanuatu
Taveuni
Niuafo'ou
Viti Levu
Fiji
Lau Group
Tonga
Aneityum
Borabora
Mangaia
Mangareva
Atherton Tablelands
Australia
Easter Island
Lake George
New Zealand
Pulbena Swamp
100°
120°
140°
160°
180°
160°
140°
120°
100°

2. Nadrau Swamp and Wainisavulevu Creek are located on the Nadrau Plateau of central Viti Levu, Fiji's largest island. The sites lie near the boundary between the forest of windward southern and eastern Viti Levu and the *talasiga* (or sunburnt) grasslands of leeward northern and western Viti Levu. The latter are generally assumed to be of anthropogenic origin (Twyford and Wright 1965; Parham 1972), but this has not been resolved. The sites were chosen in the hope that their pollen records will shed some light on *talasiga* origins.

3. Several sites in the Rewa and Navua Deltas of south-eastern Viti Levu were selected for two reasons. Firstly, both areas were the foci of intensive prehistoric human activity and their vegetation histories might reveal the effects of humans on the wetter environments of windward Fiji (c.f. the records from the Nadrau Plateau which will reflect change in the drier areas of Fiji). Secondly, the sites are close to present sea level and their stratigraphies and vegetation histories might elucidate the movements of Holocene sea levels.

It is hoped that this range of sites will provide a substantial overview of environmental change in Fiji, and thus extend our understanding of change in oceanic island settings.

The thesis is structured with an initial discussion of late Quaternary environmental change in the Australasian region, in the remainder of this chapter. A description of the Fijian environment follows (Chapter 2). The modern pollen rain in Fiji is described and discussed in Chapter 3. Then each of the pollen sites is described and the analyses are discussed in Chapters 4, 5, and 6. A discussion chapter (Chapter 7) follows which attempts to synthesize the information and present a summary of environmental change in the Fiji Islands. A final summary chapter (Chapter 8) assesses the relationship of this oceanic island record of change with other research within the Australasian region.

1.3 Vegetation and Climatic Change

The proceedings of the first CLIMANZ conference (Late Quaternary Climatic History of Australia, New Zealand and Surrounding Seas; Chappell and Grindrod 1983) compared records of environmental change from tropical and temperate parts of the Australasian region (which here includes New Guinea, Australia, New Zealand, and the south-west Pacific - places mentioned in the text are shown on Figure 1.1) and demonstrated that broadly synchronous climatic changes have occurred within the region during the late Quaternary. The evidence for climatic change reviewed by the CLIMANZ contributors is derived from long and detailed palynological records, geomorphological evidence, and records from deep sea cores. There are no terrestrial records of long-term climatic change from the islands of the south-west Pacific and much of the following review is of necessity based upon the evidence obtained from the Australasian region in general. The apparent synchroneity of late Quaternary climatic change across Australasia suggests that it is reasonable to summarise the evidence and present it as a framework for assessing environmental change in Fiji.

There is much information from this region which extends well back into the Pleistocene; for example, the palynological records from Lynch's Crater, Atherton Tableland, north-east Queensland (ca. 180 000 years old; Kershaw 1976, 1981); Pulbeena Swamp, Tasmania (ca. 65 000 years old; Colhoun *et al.* 1982); and Lake George, New South Wales (ca. 730 000 years old; Singh and Geissler 1985). The well-dated sequences with most information, however, are largely restricted to within the limit of radiocarbon (^{14}C) dating (i.e. the last 40 000 years or so) and are mainly concerned with the cycle of the last glaciation and the subsequent climatic amelioration. A review of the environmental information for this period in Australasia is given below. To facilitate discussion the period has been divided into three sections: the last glacial maximum from about 18 000 to 15 000 years before present (BP); climatic amelioration, 15 000 to 10 000 BP; and the Holocene, 10 000 BP to the present.

1.3.1 The Last Glaciation: 18 000 to 15 000 BP

Temperatures during the last glaciation probably reached a minimum at 18 000 BP (CLIMAP 1976), although cooling was initiated at a much earlier date and the minimum temperatures may have been experienced earlier in different places (Salinger 1981). Temperature reduction is recorded at sites in Australasia from about 35 000 BP (Aharon 1983; Chappell 1983; Hope 1983; Singh and Geissler 1985).

At the height of the last glaciation there were approximately 2000 km^2 of ice in the highlands of Papua New Guinea and Irian Jaya, compared with the present extent of 8 km^2 (Hope and Hope 1976). The snowline was at about 3600 m, some 900 to 1100 m below the present level (Loffler 1982). Pollen analyses from Sirunki (Walker and Flenley 1979), Mt Wilhelm (Hope 1976) and the Wahgi Valley (Powell 1970) in the New Guinea Highlands, indicate that the forest limit was about 1500 m below the present level of 3800 m and, as a corollary, alpine vegetation was much more widespread. Cold tolerant taxa were apparently most common between 18 500 and 16 000 BP (Hope 1983). It was not a simple case of depression of the vegetation zones. Upper montane rainforest was much more widespread and occurred closer to the contemporary treeline than it does today. Subalpine forests were restricted or non-existent and *Cyathea* formed a part of the vegetation above the treeline, in contrast to its present distribution below the treeline (Hope 1980).

These data suggest mean annual temperatures in the highlands were 8 to 10°C below present (Walker and Flenley 1979; Walker and Hope 1982). This contrasts with the CLIMAP (1976) prediction of a 2°C reduction in average annual sea surface temperatures in the New Guinea region at this time, based upon the biotic assemblages and oxygen isotope stratigraphy of deep sea cores. Increased lapse rates have been postulated (Nix and Kalma 1972; Walker and Flenley 1979; Loffler 1982) although Webster and Streten (1978) alternatively suggest that either sustained cold air incursions from higher latitudes induced altitudinally lower freezing levels in the highlands, or that the CLIMAP estimates were simply too conservative for this region. The latter suggestion is echoed by Aharon (1983) who reports temperatures up to 4°C lower than present for the period immediately preceeding the glacial maximum, based upon $^{16}O/^{18}O$ isotope ratios from coral reef terraces on the Huon Peninsula.

In northern Sumatra the pollen data from Pea Sim-Sim indicate a mosaic of "alpine" vegetation and upper montane forest existed in the Toba Plateau area prior to 16 500 BP, suggesting that the vegetation zones were 350 m lower than the present (Maloney 1980, 1985). Maloney does not suggest how much temperature change this might represent, but Morley (1982a) interprets a similar altitudinal depression of vegetation zones near the Danau Padang site in central Sumatra in terms of a 2°C reduction from present means. Palynological data from Lake Di-Atas at 1535 m in Sumatra also suggest a 260 m or so depression of vegetation boundaries before 12 000 BP (Newsome 1984, quoted in Flenley 1985). This represents a much less significant degree of temperature change than the New Guinea data imply, which Morley suggests is consistent with a view that the zonation of vegetation on equatorial mountains was compressed at the last glacial maximum, with minimal contraction of the lower altitude vegetation zones. However, Mt Kinabalau in Borneo was substantially glaciated (Flenley and Morley 1978), so high altitude sites were probably experiencing conditions as extreme as those prevailing in New Guinea.

Temperature data from tropical Australia are lacking for this period, but in temperate Australia, slope instability at high elevations suggests possible periglacial activity associated with lower temperatures (Costin and Polach 1971). Palynological data from the region (Kershaw *et al.* 1983a; Martin and Polach 1983) are indicative of lowered treelines and widespread alpine grasslands and herbfields in the highlands. At lower elevations more open vegetation than present prevailed. At Lake George the forest was replaced by herbaceous communities at about 22 000 BP and remained so throughout the cold phase (Singh and Geissler 1985). All of these data suggest some 6 to 10°C of temperature reduction for south-eastern Australia.

Geomorphological and palynological evidence from New Zealand indicate a lesser degree of temperature reduction. The treeline was depressed from about 1500 m to 900 m, and grassland and shrubland dominated the uplands and broad areas of the lowlands. Forest was restricted in area, but persisted in isolated, favourable sites throughout the landscape (McGlone 1985). Coupled with glacial evidence this indicates temperatures 4 to 5°C lower than present, probably accompanied by windy conditions, periodic drought and incursions of freezing polar air masses (McGlone 1983a, 1985).

It has also been suggested that the glacial maximum was an arid phase, especially at low latitudes (Williams 1975, 1985; Rind and Peteet 1985). In north-eastern Queensland, rainforest dominated by the gymnosperms, *Araucaria*, *Podocarpus*, and *Dacrydium* was gradually replaced by sclerophyll vegetation, mainly *Casuarina* and *Eucalyptus*, at about 30 000 BP. By 25 000 BP all rainforest taxa had disappeared from the record. Kershaw (1976, 1983a) interprets this as evidence for effective precipitation levels possibly 50% lower than present for the gymnosperm period, followed by intensification of aridity during the glacial maximum. Kershaw (1983a) and Ash (1983) suggest that rainfall may have been reduced partly because the exposed continental shelf widened the coastal plain adjacent to Atherton by some 70 km and moist prevailing winds had to pass over 70 km more of exposed continental shelf.

Lower precipitation levels are also indicated by the palynological records from southern Australia, in which more open vegetation is suggested (Dodson 1975, 1977, 1979; Hope 1978). From geomorphological evidence, Bowler (1983a) has postulated intensified aeolian activity over much of southern Australia associated with a major surface water deficit.

The data from the south-west Pacific for the last glacial are few and enigmatic. Spriggs (1981) comments on a ^{14}C date of 22 400 BP from the base of an alluvial terrace on Aneityum (Vanuatu) which he relates to a period of climatic change, probably an arid phase, sufficient to cause vegetation disturbance and erosion of the hillslopes. Latham (1979) records valley incision on Lakeba (Fiji) which he suggests represents an arid phase, probably in the late Pleistocene, although there are no dates to substantiate this. It seems likely that both events may be related to the last glacial, when conditions are assumed to have been arid. Based on a general circulation simulation model for 18 000 BP, Rind and Peteet (1985) suggest the annual precipitation in the western Pacific was reduced by 580 mm, which represents a reduction of 25 to 50% from present annual rainfall in the region.

Evidence of former glaciations on Mauna Kea in Hawaii, in the eastern Pacific, has allowed Porter (1979) to document a glacial chronology for the islands. The last glaciation is bracketed by ^{14}C dates of 29 000 and 9100 BP and it is suggested that during this time the snowline reached a minimum altitude of 3780 m, about 900 m below the present theoretical snowline. This may be attributed to a temperature reduction of 5°C from present values, but in attempting to explain the discrepancy between this estimate and the CLIMAP (1976) estimate of only 1 to 2°C of temperature reduction at sea level, Porter (1979) postulates that a minimum amount of temperature reduction coupled with increased precipitation may have had the same effect of lowering the snowline at high altitudes. This is in contrast to evidence of widespread glacial aridity at low latitudes (Flenley 1979a; Rind and Peteet 1985), with convincing data from South America (van der Hammen 1974), the Galapagos Islands (Colinvaux 1972), Easter Island (Flenley 1979b; Flenley and King 1984), northern Australia (Jennings 1975; Kershaw 1983a), India (Singh *et al.* 1974), and Africa (van Zinderen Bakker and Coetzee 1972; Williams 1975, 1985).

A minimum amount of temperature reduction is indicated for the tropical south-west Pacific region at 18 000 BP, according to the CLIMAP (1976, 1981) predictions of sea surface temperatures. However, the palynological and stratigraphic evidence from Easter Island, where CLIMAP predicts no temperature reduction in the last glaciation, indicate cooler conditions from 21 000 to 12 000 BP (Flenley 1979b; Flenley and King 1984). As was discussed above, in relation to New Guinea and Hawaii, much of the terrestrial evidence refutes the CLIMAP predictions for the tropics. Aharon (1983) suggests that the amplitudes of palaeoclimatic events with a period of less than 10^4 years are underestimated in the fossil abundance curves of the deep sea cores, and that the curves are further smoothed by the CLIMAP factor analysis. Quinn (1971) has postulated that cool upwelled waters persisted in the western Pacific (near Nauru and Ocean Island) during the last glaciation. This indicates that equatorial cooling extended further across the tropical Pacific than the CLIMAP data allow.

Rind and Peteet (1985) used the CLIMAP (1981) boundary conditions as input to a general circulation model. The results did not compare well with terrestrial data for snowlines and inferred temperatures from pollen evidence, but by reducing the boundary sea surface temperatures by a uniform 2°C in a second simulation, a much better fit with the land-based data was achieved. This applied for the available data from New Guinea, although temperatures remained too high for Hawaii. The relationship between increased precipitation and snowline depression in Hawaii as proposed by Porter (1979) is considered possible by Rind and Peteet

(1985) but they suggest that not enough is presently known of the conditions necessary to maintain tropical glaciers at a substantially lower altitude than the mean freezing level.

Other simulation models of the general circulation during the last glaciation (Gates 1976; Manabe and Hahn 1977; Webster and Streten 1978; Peterson *et al.* 1979) concur on the likelihood of aridity at low latitudes.

1.3.2 Climatic Amelioration: 15 000 to 10 000 BP

Ice retreat in the mountains of New Guinea began at about 15 000 BP, and by 9000 BP most areas were ice free (Loffler 1982). Vegetation communities began to assume their present distribution from this time as subalpine forest expanded from its very limited glacial distribution, and upper montane forest migrated upslope. Because subalpine forest was so restricted during the last glaciation, upper montane forest often directly replaced subalpine grassland below 3000 m as the climate ameliorated (Hope 1980). The treeline began to rise from 17 000 to 16 000 BP near Sirunki and upper montane forest arrived at about 14 000 BP, although forest vegetation did not persist until 9000 BP (Walker and Flenley 1979). The present forest limit was reached by 13 000 BP near Sirunki, by 10 000 BP near Ijomba Mire in Irian Jaya (Hope and Peterson 1976) and by 8300 BP on Mt Wilhelm (Hope 1976, 1980). Throughout the New Guinea Highlands the vegetation was close to its present distribution and zonation by 9500 BP. Both the retreat of the glaciers and upward movement of the treeline suggest a fairly rapid increase in temperatures, perhaps 3°C per 1000 years between 16 500 and 13 500 BP and subsequently a slower increase, achieving present temperatures by 9000 BP (Walker and Flenley 1979).

The treeline vegetation which moved upslope was characterised by the opportunistic dispersal of individual taxa, rather than migration of distinctive vegetation communities into what was a sudden expansion of land suitable for forest growth. Thus different high altitude vegetation communities appeared in different areas and the synthesis of these forests is ongoing (Walker and Flenley 1979; Walker and Hope 1982). The present zonation of vegetation became established only in the post-glacial period. Lower altitude forests in New Guinea seem to demonstrate a more balanced composition during the late Quaternary but it is more than likely that the environmental conditions of the last glaciation, and the consequent lowering of the treeline, had some effect on the forest composition at lower elevations in New Guinea, and that recovery from these changes is also ongoing (Walker and Flenley 1979).

Deglaciation of Mt Kinabalu in Borneo, to the north-west of the region, had occurred by at least 9000 BP (Flenley and Morley 1978).

In south-eastern Australia, climatic amelioration apparently began at about 15 000 BP marked by the onset of organic deposition in the highlands. Further climatic amelioration is suggested at about 11 000 BP with the areal expansion of organic deposits at several sites and evidence for forest expansion (Kershaw *et al.* 1983b). Upward movement of the treeline is indicated during this period suggesting rising temperatures to approximately present levels. Evidence from the Lake George sediments indicates a slow rise in temperature (Singh and Geissler 1985).

A similar situation prevailed in New Zealand. Forest expansion commenced around 14 500 BP reaching its maximum areal extent by about 10 000 BP in the North Island, and by 9500 BP in the South Island. McGlone (1983b) suggests three phases of rapid climatic amelioration for New Zealand at 14 500 BP, 12 500 BP and 10 000 BP, rather than a gradual improvement in climate. He suggests both temperature and precipitation increased by indeterminate amounts. McGlone (1985) comments that there was no consistent north to south progression of afforestation, neither did forests appear earlier at lower elevations. Afforestation was also rapid, occurring in only 500 years on the South Island, and there was no successional progression through vegetation communities. These facts point to widespread survival of forest trees in New Zealand during the glaciation. Subsequent vegetation changes then depended upon how rapidly individual taxa were able to take advantage of the change and expand their population. This appears to be very similar to the situation in the New Guinean Highlands.

The replacement of sclerophyll vegetation by rainforest species on the Atherton Tableland in tropical eastern Australia suggests that precipitation levels increased, although this occurred rather later than the main period of climatic improvement elsewhere in Australasia (Kershaw 1976). Organic sedimentation recommenced at about 10 500 BP at Lynch's Crater and similar sedimentation began sequentially at different sites across the Atherton Tableland, until finally at Quincan Crater at 7200 BP (Kershaw 1971), suggesting a progressive increase in effective precipitation across the tableland (Kershaw 1983b). Kershaw (1983b) and Ash (1983) suggest that the later date for climatic amelioration may be a local effect related to the rise in sea level which may have had a strong influence on precipitation levels in this area.

Information on post-glacial climatic amelioration in the south-west Pacific is extremely limited. That conditions approached the present situation probably sometime during this period, in line with events elsewhere in the region, is suggested by the generalised oxygen isotope curves from the Pacific, which indicate a gradual increase in temperature from about 15 000 BP to a maximum at about 8000 BP (Shackleton and Opdyke 1973; Hays 1983). In Hawaii Porter *et al.* (1977) indicate that the last glacial ice cap had disappeared from Mauna Kea by at least 9000 BP. Since eight metres of sediment underly this dated organic horizon in a glacial lake basin it is likely that deglaciation had occurred up to several thousand years earlier.

1.3.3 Holocene: 10 000 BP to Present

While conditions during this period approximated the present throughout Australasia, there is some evidence for an early to mid-Holocene climatic optimum. Unfortunately vegetation records become more difficult to interpret in climatic terms during the Holocene because of the likely increased impact of man on the environment. However, in Papua New Guinea there is pollen evidence for an expansion of forest above the present treeline between 8600 and 5000 BP (Hope 1976) which is attributed to possibly higher temperatures and a lower frequency of intense frosts, coinciding with increased cloudiness and rainfall, at least in the highlands. Subsequently, a depression in the treeline may have been due to either more severe climatic conditions, the clearing activities of man (who was probably present in the highlands from 9000 BP; Golson 1977), or a combination of both factors. Certainly there was an increase in taxa suggestive of forest disturbance from this period at many sites throughout New Guinea.

In south-eastern Australia there was an expansion of wet sclerophyll forest in the early to mid-Holocene with a cluster of dates around 9000 to 7000 BP in the highlands, and 6000 to 4500 BP in the lowlands (Bowler *et al.* 1976; Hooley *et al.* 1980; Kershaw *et al.* 1983c). Indications are that conditions were wetter, at least in the lowlands, and perhaps warmer and wetter in the highlands than either before or since.

More equable climates are indicated for New Zealand from about 10 000 BP until 5000 BP by the presence of abundant *Dacrydium*, *Ascarina* and treeferns in the vegetation. The subsequent reduction in these taxa is explained with reference to an increase in the occurrence of droughts and frosts in the past 5000 years (McGlone and Moar 1977; McGlone 1983c).

A similar optimum of climatic conditions is indicated for tropical Australia where vegetation patterns suggest rainfall may have been 50% higher than present from 7000 to 3000 BP and that temperatures may have been slightly lower due to increased cloud cover (Kershaw 1983b).

No such climatic optimum is recorded in the Sumatran pollen diagrams, but

Morley (1982a) suggests that pollen analysis may be unable to detect minor vegetation changes in these floristically complex areas, or that the change was not experienced at low altitudes in the tropics.

Data from the south-west Pacific are even more enigmatic during this time. Archaeological research suggests humans have been present in the south-west Pacific for some 3500 to 4000 years and that during this time have modified the vegetation considerably. However, there is little evidence for climatic change. Selling's (1948) undated pollen diagrams from Hawaii indicate the expansion of warmth-demanding taxa at the expense of more cool-adapted taxa. This may correspond with the temperature maximum at 8000 to 9000 BP suggested by the oxygen isotope curves from deep ocean cores (Hays 1983).

1.4 Sea Level Change

By far the most significant event of the past 18 000 years or so throughout the islands of the south-west Pacific was the low glacial sea level followed by the rapid post-glacial marine transgression. While sea level varies differently in different places due to local isostatic and tectonic movements, glacio-eustatic sea level records suggest that at the height of the last glacial, sea level was probably 140 m below present levels. In the ensuing 12 000 years, to about 6000 BP, sea level rose at an average of one metre per 100 years (McLean 1980; Chappell 1982). There is some dispute as to whether sea level reached present levels at about 6000 BP and has remained more or less stable since, whether sea level has been higher than present levels in the past 6000 years, or whether there has been a gradual rise to present levels during that time (and examples of each pattern of sea level change exist within the Pacific region: Bloom 1970; Easton and Olson 1976; Easton and Ku 1980; Chappell *et al.* 1982), but it is likely from the available evidence that there have been no eustatic fluctuations of more than one metre since 6000 BP (Chappell 1982).

At the sea level minimum, the size of many islands of the south-west Pacific was dramatically increased, presently separate islands were joined to form larger islands, and many more islands were emergent than are at present. While none of the oceanic islands of the south-west Pacific would have assumed continental proportions at this time, opportunities for migration of the terrestrial biota would have been increased and drainage and sedimentation patterns were likely to have been dramatically different. McLean (1980) suggests that many small volcanic islands, for example Lakeba and Koro in the Fiji Group, have surface features primarily determined by sea level change. Similarly, the nature and stability of small island ecosystems is also likely to be a reflection of major shifts in sea level.

Global post-glacial sea level rise has been modeled by Clark *et al.* (1978) and Clark and Lingle (1979). The former suggest there are six geographic zones which have differing characteristic sea level responses to uniform melting of the northern hemisphere ice sheets. In the second model, the predictive sea level rise of the first is combined with the predicted retreat of the Antarctic ice sheet and the distribution of the original six zones is modified to account for this. Most of the south-west Pacific region falls within zone IV of Clark and Lingle's classification. This zone is predicted to be characterised by a lack of emerged beaches and a slow rate of submergence.

The data which are available from the region are few and each record differs. Bloom (1980) has noted that the local tectonic history is the major factor in Holocene sea level displacement on Pacific islands. This underlines the need for a sea level history to be constructed for each area of interest, and the difficulty in producing a regional synthesis of the Pacific. To the west of the region, Chappell *et al.* (1982) have demonstrated that sea level in the Palm Island Group and the southern Gulf of Carpentaria reached a maximum at 5500 BP and then fell, more or less steadily, to the present level. This contrasts with the available records from oceanic islands in the Pacific, for example the eastern Caroline Islands, where the rate of sea level rise slowed at 6000 BP and has been steadily approaching the present since then (Bloom 1970), and Hawaii where a similar pattern of relative sea level change has occurred (Easton and Olson 1976). The results of all these studies are compatible, however, when the sea level fluctuations due to hydro-isostatic deformation of the shelf caused by the increased weight of water are considered. In the absence of a continental shelf in mid-oceanic situations, the rise in sea level relative to land has probably been gradual and consistent in the past 6000 years as Clark and Lingle (1979) predict.

The data from Fiji are equivocal, and restricted to sites on the main islands of Viti Levu and Vanua Levu. Schofield (1970) surveyed beach ridges in southern Viti Levu and suggested that the sea had fluctuated about 1 m above and .6 m below its present level during the late Holocene, although no dates confirm this. Sugimura *et al.* (1983) and Matsushima *et al.* (1984) outline a more detailed Holocene sea level record based on the evidence of ^{14}C dates, sediments and a marine diatom flora from two cores extracted from a coastal plain in southern Viti Levu. They suggest that sea level was about 1.2 m below present at about 4400 BP and about 1.6 m above present sea level between 3000 and 2000 BP. However, this was not substantiated by cores extracted nearby during fieldwork for this thesis and the surface levels of the cores were relocated and relevelled and found to be in error by approximately ∓1.1 m. This effectively reduces the upper level of a marine diatom flora in the cores to .48 m above present mean sea level, which is within the present tidal range. A reinterpretation of the stratigraphy and the ^{14}C dates suggests that there is no substantial evidence for higher sea levels during the Holocene, and for at least the past 1600 years, sea level has been close to the present level (Ash and Ash 1985). In a later publication Maeda *et al.* (1986) present a revised sea level curve for southern Viti Levu which incorporates the new levels of Ash and Ash (1985) and suggests sea level reached its present position at about 4000 BP, and was perhaps marginally higher between 4000 and 3000 BP.

Bloom (1980) reports a single uncorrected ^{14}C date of 5500+/-110 BP on peat from 4.5 m below present sea level in the Rewa Delta. He suggests that sea level followed a similar curve as that derived from the eastern Caroline islands (Bloom 1970). These interpretations agree with the predictive model of Clark and Lingle (1979) for this region.

Maeda *et al.* (1986) report on emerged wave-cut notches in limestone on the south-eastern coast of Vanua Levu. They suggest that these represent a Holocene sea level higher that the present, although dating is restricted to a single uncorrected ^{14}C date on coral (3790+/-170 BP) and interpretation is complicated by an indeterminate amount of tectonic uplift in the area.

1.5 Human Impact on the Environments of the South-West Pacific

Evidence exists to suggest that human activities have substantially modified environments wherever settlement has occurred. Kirch (1982a) discusses Anderson's (1952) concept of "transported landscapes" in which Kirch suggests the colonisers of new lands bring "a cultural concept of landscape, which causes them to actively shape a new environment in that mold" (Kirch 1982a: pp 2-3). In the Australasian region, two distinctive patterns and timescales of human occupation emerge. Firstly, the continental land-masses of Australia and New Guinea have supported human populations for lengthy periods of time during which large-scale climatic changes have occurred. It is thus difficult to clearly distinguish between anthropogenic influences on the vegetation and other natural influences. Secondly, the islands of the south-west Pacific have been occupied for much shorter periods during which climatic change has been at a minimum and it is therefore likely that human impact on the environment may be more clearly defined. The second of these patterns of change is relevant to this study and will be examined below.

Kirch (1983) has suggested that in the south-west Pacific region there are three major processes of environmental modification due to human impact. Firstly, the deliberate introduction by man of a variety of adventive species such as the domestic animals (e.g. pigs, dogs and fowl), and the inadvertent introduction of other species (e.g. rats, landsnails and weeds). The impact of these introductions on the previously isolated ecosystems of oceanic islands probably placed the largely endemic biotas in disadvantageous competition with the often vigorous adventives. Secondly, there may be direct displacement of the indigenous biota by such activities as forest clearance and the exploitation of wild food resources. Finally, human activities may cause some modification to the physical environment, especially to the processes of erosion and deposition, and the rearrangement of landscapes through the construction of terraces and field irrigation systems. Islands in the subtropics or those parts of tropical islands which experience a pronounced dry season are particularly vulnerable.

Palynological studies are suited to yield information on these topics. Man-induced changes in the vegetation, for example clearance, or the presence of cultivated and adventive plants may be reflected directly in the pollen spectra of swamp and lake sediments. Sediments may also contain a record of the fire regimes in the past in the form of microscopic carbonised particles. Deposition rates and the nature of the sediments may give some indication as to the stability or otherwise of slopes nearby. Coupled with geomorphological and archaeological information, the palynological data may be used cautiously to examine the role of man in environmental change (e.g. Gillieson *et al.* 1985).

The information presently available for the south-west Pacific suggests that there has been a consistent pattern of environmental change related to human activity across the region. The history of anthropogenic environmental modification in Fiji will be placed in the context of this regional pattern.

The earliest archaeological sites in island Melanesia and western Polynesia contain abundant remains of Lapita pottery which is characterised by its distinctive impressed decorative style (Spriggs 1984a). The origin of this culture group probably lies in the Bismarck Archipelago and its dispersal to the east probably occurred from about 4000 BP (Allen 1984; Gosden and Allen 1984). The earliest dates for Lapita sites outside the Bismarcks are 3500 BP (White and Allen 1980; Spriggs 1984a). The distribution of the Lapita people is closely linked with the spread of the Oceanic-Austronesian group of languages (Pawley 1981; Pawley and Green 1984). The artifactual assemblages in Lapita archaeological sites are suggestive of an agricultural component in the technology of the earliest settlers (Allen 1984).

Knowledge of deliberate aboriginal introductions of plants and animals to the

Pacific islands is limited. Some indication of introduced weed species which were observed at the time of european contact are available for Hawaii and Fiji, and include *Ludwigia octovalvis*, *Oxalis corniculata*, *Urena lobata*, *Thelypteris interrupta*, *Digitaria setigera*, *Waltheria indica* and *Merremia aegyptia*[2] (Parham 1959; Kirch 1982a). Direct evidence of the introduction of weeds has been obtained from the Mauna Kea Adz Quarry in Hawaii where seeds of the weed taxa *Oxalis corniculata*, *Daucus* sp., *Solanum nigrum*, and *Adenostemma lavenia* have been found in archaeological contexts (Allen 1981, quoted in Kirch 1983).

The most commonly occurring introduced taxa found in early occupation sites throughout the Pacific islands are the domestic animals: pigs, dogs and fowl. Skeletal remains of these animals have been recovered from early sites in Fiji (Hunt 1981), Hawaii (Kirch 1982b), and Tikopia (Kirch 1983). The presence of domestic animals is often taken as an indication that horticultural activities were also practised by founding populations (Kirch 1979).

Many Pacific islands support large areas of depauperate vegetation communities, largely consisting of grasses and ferns, which are assumed to be anthropogenic in origin. Contributing activities include burning and clearing with resultant erosion, topsoil loss and reduction in soil fertility. Kirch (1983) has suggested that the use of fire in forest clearance was the major cause of environmental transformation in the Pacific. Vegetation communities of this type have been recorded from several islands in Fiji (Parham 1972; Garnock-Jones 1978; Latham 1979), Aneityum in Vanuatu (Spriggs 1982), Futuna and Alofi, Horne and Wallis Islands (Kirch 1981), Hawaii (Kirch 1982a), Huahine, 'Uvea, Mangaia, Borabora and Mangareva in western Polynesia (Kirch 1982b), and parts of New Zealand (McGlone 1983d).

Taxa which are common in these open vegetation communities across the south-west Pacific region include ferns of the Gleicheniaceae, especially *Dicranopteris linearis*, and Lycopodiaceae, especially *Lycopodium cernuum*. In Hawaii these ferns are accompanied by various grasses and taxa which tolerate light and regenerate after fire, for example, *Tacca leontopetaloides*, *Sadleria* and *Rhus sandwicensis*. It is suggested by Kirch (1982a) that this vegetation community replaced a native forest dominated by *Acacia koa* with *Erythrina*, *Reynoldsia*, *Myoporum*, *Diospyros*, *Nothocestrum*, *Rauvolfia*, *Canthium* and *Santalum*. On Futuna and throughout Fiji the degraded vegetation communities are dominated by *Dicranopteris linearis*,

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[2] **Plant species mentioned in the text are listed with their authorities in Appendix A. Except where indicated, nomenclature follows Smith 1979, 1981, 1985 for gymnosperms and angiosperms, and Brownlie 1977 for pteridophytes.**

Miscanthus floridulus and *Casuarina equisetifolia*, with *Pteridium esculentum* in Fiji and the orchid *Spathoglottis pacifica* in Futuna. In places, introduced grasses have displaced the native species (Parham 1972; Kirch 1981). The original vegetation, at least for leeward Fiji, was probably a light forest consisting of *Acacia richii*, *Syzygium richii*, *Casuarina equisetifolia*, *Mussaenda raiateensis*, and *Morinda citrifolia*, with the shrubs *Dodonea viscosa*, *Hibbertia lucens*, *Leucopogon cymbulae* and *Decaspermum vitiensis* (Parham 1972).

In the more temperate environments of New Zealand, *Pteridium esculentum* is the common fern present, although with continued firing it may be replaced by a grassland community (McGlone 1983d).

While there are obvious floristic variations in these open vegetation communities between the different islands, the dominance of the grass/fernland formation, its likely anthropogenic origin and the maintenance of each community by regular burning are common features.

Evidence for prehistoric clearance and burning and the origin of these vegetation communities has been obtained from palynological and geomorphological studies. The dates for this clearing on Pacific islands tend to correspond with archaeological evidence for the original settlement of such places. In Fiji, Hughes *et al.* (1979) have documented increases in sedimentation rates from about 2000 BP in lowland swamps on the island of Lakeba. This coincides with the estimated time of arrival of humans on Lakeba (Rowland and Best 1980). High frequencies of carbonised particles in the sediments suggest that fire was a likely tool for clearance to facilitate shifting cultivation. The massive catchment erosion which occurred during the early phase of swamp sedimentation and the indicated burning regimes suggest that the patterns were well established by 2000 BP. Hughes *et al.* (1979) and Hughes (1985) maintain that the formation of the swamps on a large scale began only with the arrival of people and the subsequent environmental disturbance. The large swamps then provided an ideal environment for wetland cultivation, and Spriggs (1985) comments that on Lakeba "...the evidence suggests an increasing shift in subsistence patterns over time from hillside cultivation to intensive use of the valley bottoms and swamplands" (Spriggs 1985: p 419).

It has also been suggested by Birks (1973) that the accumulation of sand at the mouth of the Sigatoka River on Viti Levu was at least partly a result of clearing in the upper catchment and mobilisation of sediment. Phases of increased sand accretion alternate with at least three phases of dune stabilisation which were characterised by soil development and establishment of vegetation. Archaeological remains on the buried soil horizons indicate quite intensive occupation of the dune area from about 2500 BP. Renewed phases of accretion date at about 1700 BP. Palmer (1968) excavated hillforts in the Sigatoka valley, but these have not been dated.

Spriggs (1982) and Hope and Spriggs (1982) have used archaeological, geomorphological, and palynological evidence to determine the sequence of environmental change on Aneityum in Vanuatu. The preliminary pollen record from Anawau Swamp indicates a forested landscape was present on Aneityum prior to 2900 BP. In the following period, to the present, the vegetation changed dramatically to open grass and fernland with scattered trees. There was a parallel increase in the concentration of carbonised particles in the sediment which suggests fire may have been a dominant tool in the forest removal. This resulted in massive erosion and the deposition of extensive alluvial plains at the mouths and along the valleys of many streams. ^{14}C dates indicate valley infilling was initiated at about 2180 BP and 1570 BP for two different valleys. While the destruction of the vegetation may have ultimately rendered the slopes unfit for the shifting cultivation previously practised, the creation of extensive alluvial flats provided an ideal environment for the cultivation of hydrophytic crops (e.g. taro) and agricultural intensification on the valley bottoms and social stratification of the human population living there has occurred in the past 1000 years or so (Spriggs 1982, 1985).

A similar sequence of events has been recorded for Tikopia in the Solomon Islands (Kirch and Yen 1982; Kirch 1983), where much of the landscape is regarded as an artifact of settlement. Ethnographic accounts suggest the native population practised active dune conservation. This, coupled with natural shoreline aggradation following rising sea level has resulted in an estimated 40% increase in the land area of Tikopia at the coast. Forest clearance on the upland slopes is suggested by the massive deposition of colluvium at the boundary between the volcanic and shoreline calcareous edaphic environments from about 1370 BP. The colluvial soils created are now the most fertile on the island and archaeological evidence suggests they became the sites of intensive agricultural activity.

On Futuna, Horne Islands, there is stratigraphic evidence for increased deposition rates in lowland sites following vegetation clearance. Kirch (1981) suggests that the degraded vegetation presently growing on Futuna is anthropogenic in origin and maintained by periodic burning.

In the Hawaiian Islands, much of the palaeoenvironmental evidence for forest clearance and the anthropogenic origin of the extensive grasslands below about 440 m asl is derived from the investigation of fossil landsnails. The abundance of several adventive gastropod taxa (e.g. *Lamellaxis gracilis*, *Lamellidea oblonga* and *Gastrocopta pediculus*) has been used to postulate the presence of man and agriculture in many oceanic archaeological contexts (Kirch and Kelly 1975; Christensen and Kirch 1981; Hunt 1981; Kirch 1982a). In the Halawa Valley on Molokai, stratified colluvial deposits contained basal gastropod assemblages which suggested the now grassy slopes originally supported an open native forest. The subsequent appearance of abundant carbonised particles in the sediments and an increase in the rate of deposition from about 800 BP are suggestive of burning and clearance followed by extensive erosion. The native gastropod assemblages are replaced by abundant "anthropophilous" species thought to be transported by man in the edaphic medium of crop plants, for example taro. Several other valleys in Hawaii also have evidence of man-induced geomorphological change (Kirch 1982a).

In New Zealand a large body of evidence has accumulated to suggest an extensive human impact on the environment. It has been widely accepted from the evidence of soils, charcoal, pollen and landsnails that prior to human settlement there were few areas below the climatic treeline which were devoid of forest or woodland vegetation. Since the arrival of the Polynesians, some 1000 to 1200 years ago, approximately 50% of this original forest has been destroyed by fire (McGlone 1983d). Geomorphological evidence suggests initiation of slope instability and erosion also from this time.

Spriggs (1985) has summarised much of this information on prehistoric man-induced landscape change and concludes that many sequences imply an initial period of dryland agriculture which resulted in massive erosion of hillsides and the formation of extensive alluvial plains in the lowlands. At a later date these areas became the centres of intensive agricultural activity focused on large-scale irrigation systems. He suggests that on both Aneityum and in the Hawaiian Islands, the alluvial agricultural systems provided the resource base for centralised chiefdoms and political units.

1.6 Summary

This review of the most recent research on Quaternary palaeoenvironments in the Australasian region allows the questions which might be answered by a Fijian example to be more clearly defined. Firstly, there are marked discrepancies between the amount of temperature reduction predicted by CLIMAP for the glacial maximum in the Australasian tropics and that which is suggested by terrestrial palynological and geomorphological records. Any additional information from terrestrial oceanic situations must help clarify whether the CLIMAP estimates are simply too conservative for this region, or whether anomalies in atmospheric circulation are more likely. A clearer picture of climatic change is also likely where there is no modification of local climates (especially local precipitation patterns) by sea level movements across a wide continental shelf.

Secondly, if the vegetation was dramatically different at the height of the last glaciation in Fiji, how long was its response time to climatic amelioration, given the almost immediate effect rising sea surface temperatures should have had upon the Fijian climate. The review presented above suggests that in continental areas, regional climatic amelioration and vegetation response were probably initially overwhelmed by more local environmental factors such as the effects of a rising sea level. Vegetation responses too may lag behind climatic change if the distances from sources of taxa are great.

Thirdly, it has been shown that post-glacial vegetation changes more often demonstrate that opportunistic taxa have taken advantage of changed environmental conditions and expanded their populations, than that vegetation communities *per se* have expanded from glacial refugia. In Fiji, where distances are not great and biogeographic barriers are unlikely, even at the glacial maximum, it may be possible to ascertain whether cohesive community behaviour is likely in the post-glacial.

Fourthly, it may be possible to determine to what extent the *talasiga* lands are an artifact of the past 3500 years of human activity, and how their origin relates to the hypothesized origin of other similar vegetation forms in the south-west Pacific. Given the stability of climates over that period, a Fijian record of environmental change should clearly demonstrate the impact of humans on the landscape.

CHAPTER 2

THE FIJIAN ENVIRONMENT

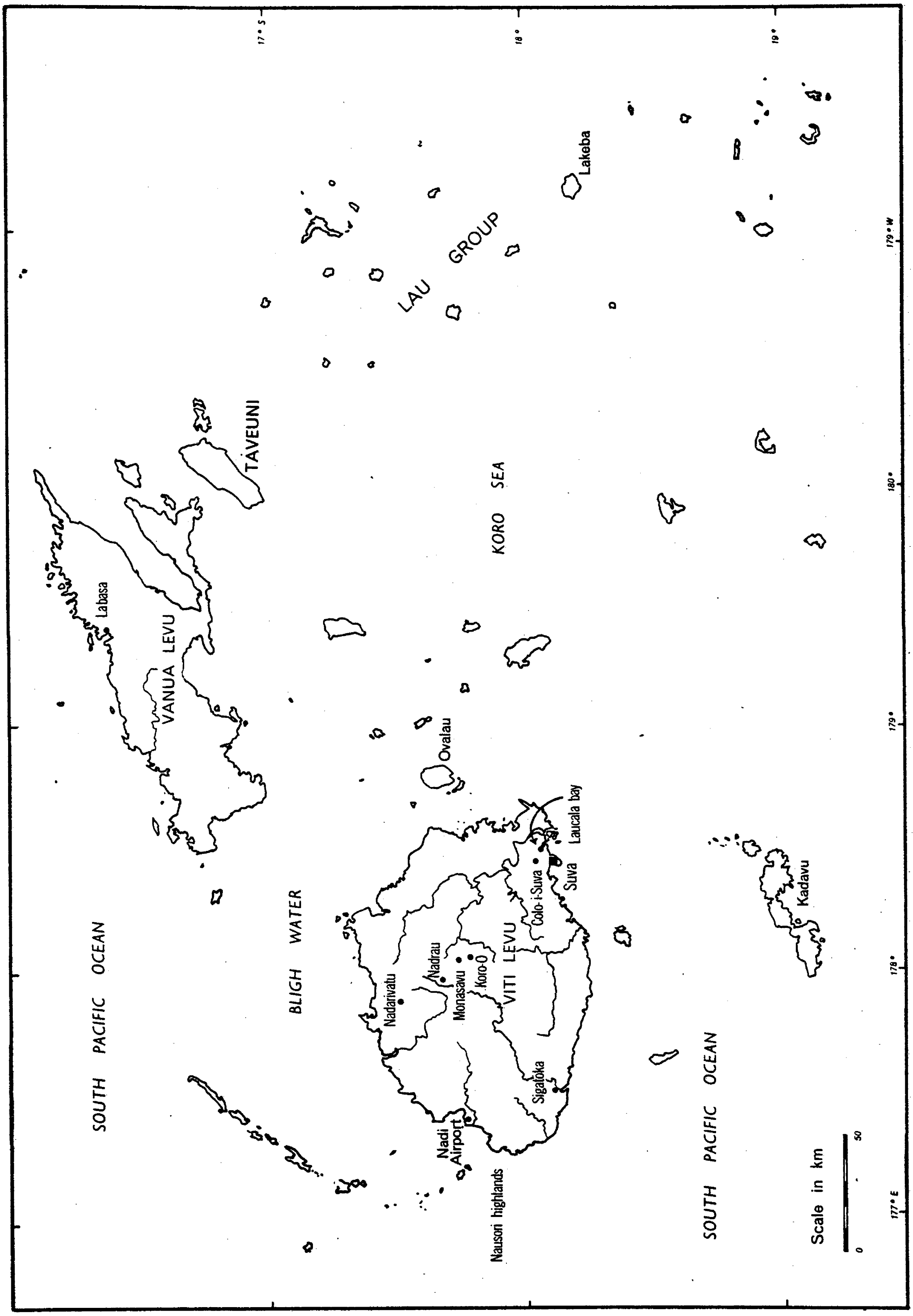
The Fiji archipelago consists of about 500 named islands and many more smaller islets (Derrick 1965) distributed between latitudes 15 and 22°S and longitudes 177°W and 175°E, see Figure 2.1. The large volcanic islands of Viti Levu and Vanua Levu together account for 89% of the total land area within the island group, and the remaining islands are therefore extremely small in area. To the west, the nearest island group, Vanuatu, is approximately 1000 km distant; and to the east the nearest neighbours are Tonga and Samoa, about 800 km away. Fiji is remote from continental landmasses, with Australia some 2500 km distant, and New Zealand about 2000 km away.

2.1 Tectonic History and Geology

The Fiji Islands are located on the Fiji Platform and Lau Ridge, and are surrounded by the deeper waters of the Vitiaz Trench to the north, the South Fiji Basin to the south, the Tonga-Kermadec Trench to the east, and the New Hebrides Trench to the west (see Figure 2.2 for the tectonic features mentioned in this section). The trenches form the boundary between the Indo-Australian and Pacific Plates and the area is known as the Hunter Fracture Zone (Rodda and Kroenke 1985). The origin of most tectonic features in the Fiji region is bound up with the relative movements of these plates.

Crook (1981) suggests the Fiji Platform developed as a new crustal block, in the form of an island arc, close to New Caledonia at palaeolatitude 30°S during the Late Palaeocene, 60 to 53 million years ago, although Rodda and Kroenke (1985) suggest that this may have occurred later, in the early Oligocene. The Indo-Australian Plate had started to separate from Antarctica and move northward, subducting under the Pacific Plate. Other new blocks formed during this period of plate movements probably included the Lau-Tonga and New Hebrides Ridges. Together with the Fiji Platform these ridges developed into the chain of island arcs which are known as the Melanesian Borderlands because of their critical location at the border between the two plates (Coleman and Packham 1976). On the basis of

Figure 2-1: Location Map of the Fiji Islands



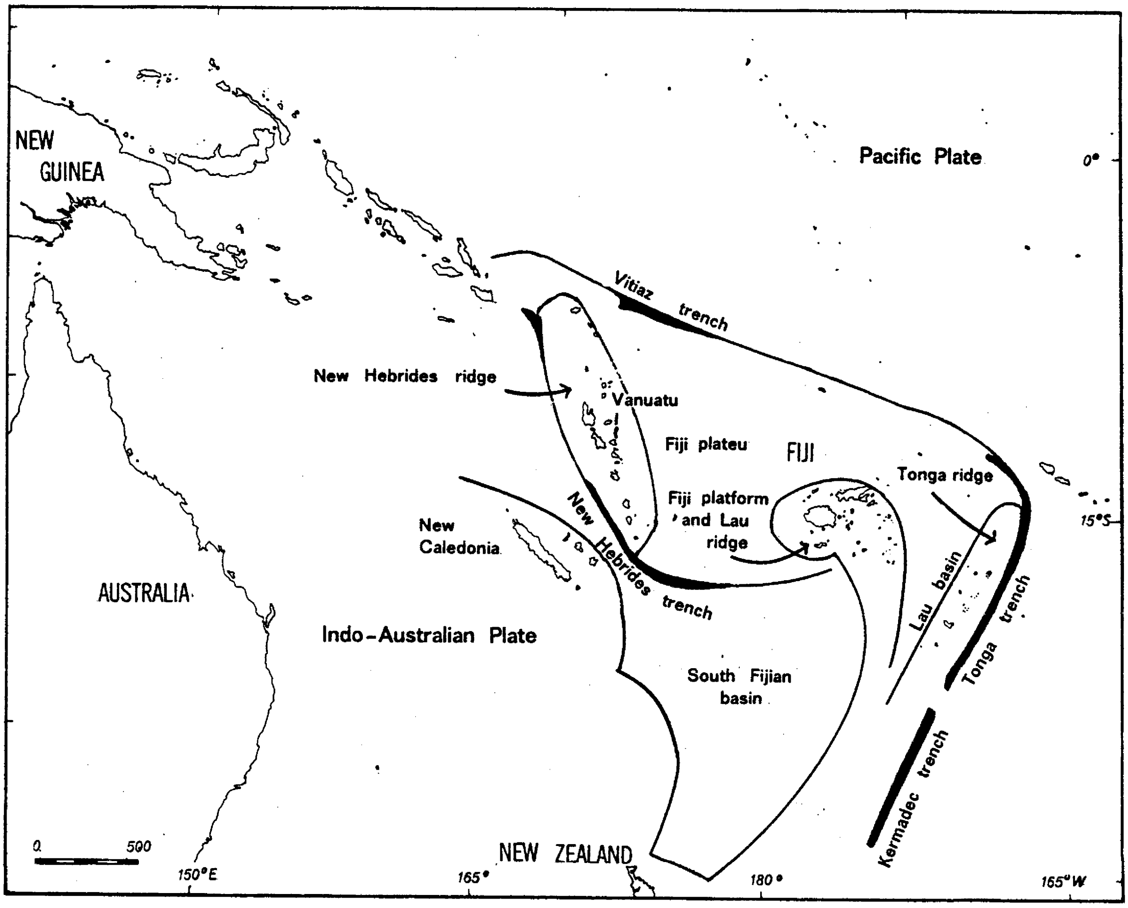


Figure 2-2: Tectonic Features in the Fiji Region

contemporaneous volcanism of similar composition throughout Fiji, Lau-Tonga and the New Hebrides Ridges, Gill and Gorton (1973) suggest they may have formed a continuous ridge at this time on the Australian side of the subduction zone.

The island arcs moved north-eastward away from the Australian landmass into the Pacific with the migration of the plates' boundary from the early Eocene to the late Oligocene (50 to 25 million BP), leaving a growing marginal sea in their wake (Gill and Gorton 1973; Coleman and Packham 1976).

In the early Miocene, about 20 million BP, retrograde motion of the island arcs towards the west had commenced in New Britain and continued south-eastwards along the chain of arcs. By the late Miocene, the New Hebrides Ridge started moving back towards New Caledonia because of initiation of subduction on its western side. To a lesser extent the Fiji Platform underwent similar movements (Coleman 1980; Crook 1981). If the New Hebrides Ridge and Fiji Platform were once continuous, it is suggested that they fragmented at about this time (Gill and Gorton 1973).

A large part of the Melanesian marginal sea was eliminated by subduction during this period and at present the New Hebrides Basin and northern part of the South Fiji Basin are all that remain of the marginal sea (Coleman 1980).

Sea floor spreading occurred at about 5 million BP as a result of the rotation of the Fiji Platform, splitting the once adjacent Tonga and Lau Ridges, and forming the Lau-Harve interarc basin between the present Fiji and Tonga Islands. This has moved the Fiji Platform, which is continuous with the Lau Ridge, away from the zone of subduction along the Indo-Australian and Pacific Plates' boundary and stranded the Fiji Islands as a remnant arc (Gill 1976). Spreading of the Lau-Harve Basin has continued up to the present with sustained eastward migration of the Tonga Ridge.

The volcanism associated with active island arc formation in the south-west Pacific consists mainly of intermediate and andesitic magmas as well as basalts. This variation appears to depend upon the relative position of the subduction zone and trench at the plates' boundary at the time of eruption, the chemical composition of the volcanic rocks varies with distance from the trench. Gill and Gorton (1973) have proposed the following model for volcanism in such zones. Closest to the trench they suggest tholeiitic volcanism producing andesitic rocks is dominant. This is replaced by calc-alkaline and then high potassium calc-alkaline volcanism resulting in basalt flows as distance from the trench increases. Notably there is increasing alkalinity and potassium content along this gradient (Ollier 1981).

Three major periods of volcanic activity have been identified in Fiji (Rodda 1967; Gill and Gorton 1973; Green and Cullen 1973); Eocene to early Miocene (50 to 20 million BP); late Miocene (9 to 5.5 million BP); and Pliocene to Recent (<5 million BP). The chemical composition of the rocks changes, tending towards increased alkalinity and potash enrichment in the younger rocks. Thus the oldest volcanics are mainly tholeiitic and andesitic, the late Miocene volcanics are largely andesitic (calc-alkaline), and most recently, from the Pliocene to Recent, the volcanic rocks consist of alkaline basalt flows and volcaniclastics (Gill 1970; Green and Cullen 1973). This sequence is similar to the model proposed by Gill and Gorton (1973) and suggests movement of Fiji away from an active oceanic trench. The two earliest periods of volcanism were likely to be associated with a subduction zone at the plates' boundary north of the Fiji Platform. The most recent volcanic rocks are quite different in that they are mainly basaltic and coupled with regional uplift they are possibly related to fragmentation of the New Hebrides-Fiji-Tonga

Ridge. This period of volcanism coincides with the opening of the Lau-Harve Basin and the rotation of the Fiji Platform (and Lau Ridge) away from the subduction zone to a remnant arc situation (Gill 1976).

The periods of volcanic activity were interrupted by periods of stillstand, characterised by lenses of foram-algal limestones and often metamorphosed volcanic sediments. Stratigraphic sequences in Fiji are most complete in Viti Levu and may be summarised as follows after Rodda (1967, 1982) and Coleman and Packham (1976).

1. The basal Wainimala Group consists predominantly of Eocene volcanic conglomerates, tuff, pillow lavas and pillow breccia (andesitic), with an upper late Eocene horizon of foram-algal limestone. Volcanic sediments are common high in the stratigraphic succession of this group. Metamorphosis to green schist has since occurred.

2. The Sigatoka Group are dominantly sedimentary rocks which lie partly disconformably and partly interfingered with the Wainimala Group. Most of the rocks are not metamorphosed. The group may date from the late Eocene to the later early Miocene, but this is not clear. Erosion and structural change mark the top of this group.

3. A period of volcanism and sedimentation (in four basins - Nadi, Ra, Rewa and Navosa) followed, and includes rocks of the Savura Volcanic Group (andesitic conglomerate, breccia, pillow lava and pillow breccia), Medrausucu Andesitic Group (pillow lava, normal flows, breccia and conglomerate) and Koroimavua Andesitic Group (which also includes sedimentary rocks). These groups date from the late Miocene.

4. The most recent (Pliocene to Recent) Group is the Ba Basaltic Group which has spread over much of Fiji. This includes lava flows, breccias, tuffs, conglomerates, and pillow lavas, dominantly of basaltic composition, but with some minor andesites. Eruptions have continued until at least 2000 years or so ago, at least on Taveuni (Frost 1974).

The nature of the basal Wainimala Group rocks suggests the lava flows were largely submarine and the fossils in the associated sedimentary facies are indicative of deposition under perhaps 50 m of water. The Wainimala section is estimated to be about 10 000 m thick which suggests deposition was accompanied by subsidence under geosynclinal conditions. Sedimentary environments during deposition of the Sigatoka Group were probably similar to the preceeding Wainimala times, that is, under shallow water conditions (Green and Cullen 1973). Orogenic activity during the Oligocene may have raised some of this material to form dryland in the Fiji Group (Rodda 1982), but the major period of dryland genesis is thought to have started in the late Miocene (perhaps since 10 million BP). Shallow water conditions have apparently prevailed at times since then (Green and Cullen 1973). Gill and Gorton (1973) suggest there has been at least 800 m of uplift on Viti Levu during the past 5.5 million years and it is during this period that consolidation of dryland conditions must have occurred.

2.2 Climate

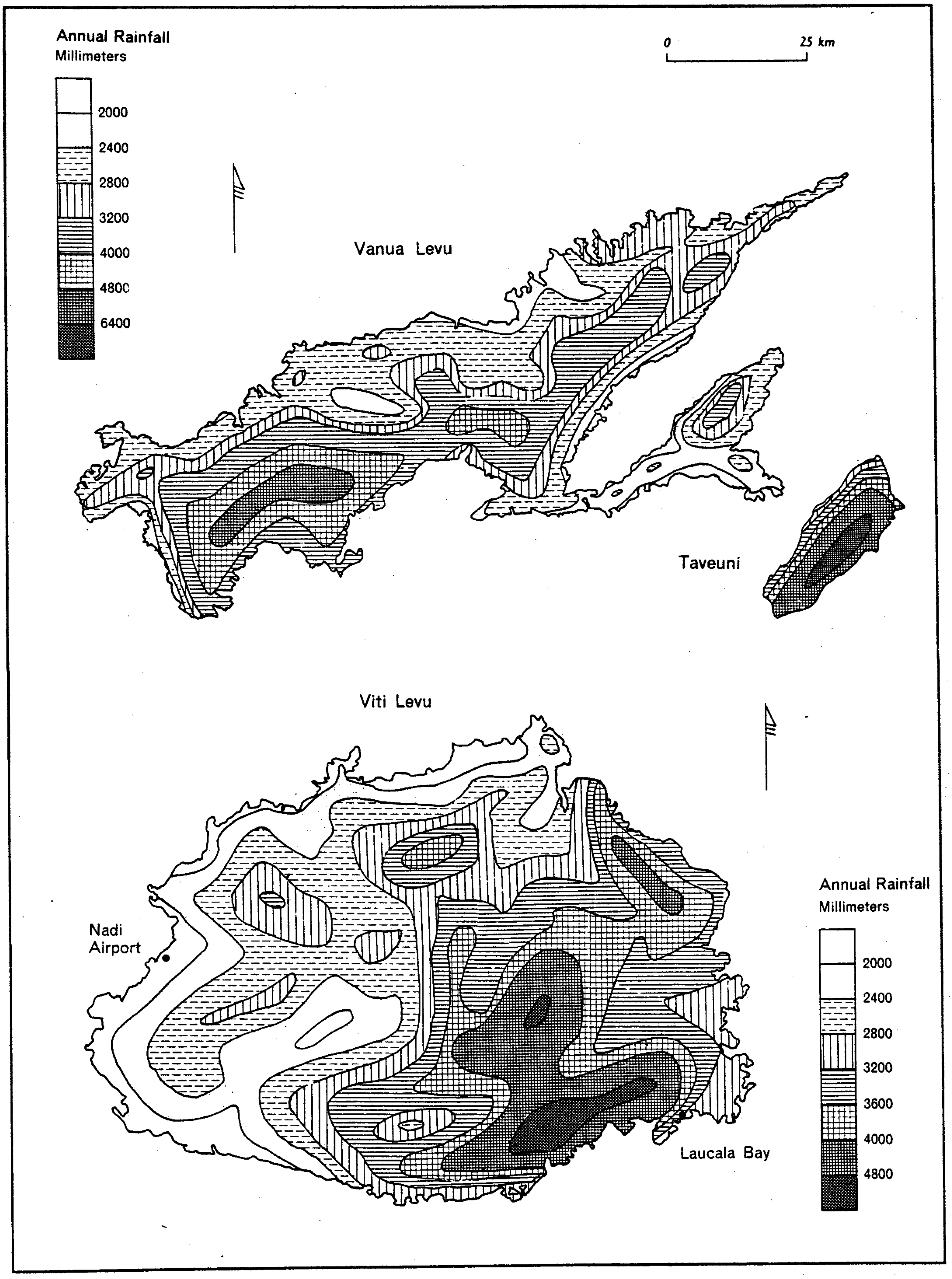
Atmospheric circulation in the tropical and subtropical Pacific is part of the east-west circulation driven by movements of air between the warmer eastern and cooler western hemispheres known as the Walker Circulation (Streten and Zillman 1984). This results in upper air westerly air movement and surface easterly flow in the form of the south-east trade winds. While these winds persist across the south-west Pacific during the winter months (April to October), they are displaced by more variable winds from the north, north-east and east during the summer period (November to March) as a result of the southward migration of the intertropical convergence zone (ITCZ) of low pressure. Although the ITCZ proper does not enter the south Pacific, a more active band of convergence (the south Pacific convergence zone - SPCZ) and accompanying convectional cloud and rain extends south-east from Papua New Guinea (Streten and Zillman 1984). Cyclonic activity in the region is most common during this period. Within this general circulation pattern, the Fiji Islands experience a tropical oceanic climate characterised by moderate to high rainfall and warm average annual temperatures.

2.2.1 Rainfall

All rainfall recording stations in Fiji show a rainfall maximum from November to April which corresponds with the presence of the SPCZ and the resultant incidence of convectional rainfall. Occasionally the convergence zone fails to affect Fiji and wet season rainfall is much reduced (Harris 1963). For the remainder of the year, while the islands are influenced by the moist south-east trade winds, moderately heavy rainfall is experienced on the south and south-eastern parts of the main high islands of Viti Levu, Vanua Levu and Taveuni which lie across the trade winds. There is a pronounced leeward dry zone in the north and west of the large high islands, and similarly, many of the small islands which have low elevation and do not induce orographic precipitation from the trade winds, experience very dry conditions from May to October. A marked windward/leeward contrast in average annual rainfall is therefore apparent for the Fiji Group (see Figure 2.3), with wet zone averages from 3200 to greater than 4800 mm per annum and dry zone averages less than 2800 mm per annum.

Laucala Bay and Nadi Airport in south-eastern and western Viti Levu, respectively, are representative of the different rainfall regimes which exist in Fiji.

Figure 2-3: Annual Rainfall Distribution in Fiji



The average monthly and annual rainfall figures for these stations are shown in Table 2.1 (for their locations see Figure 2.3).

Table 2-1: Average Rainfall for Fijian Stations

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Laucala Bay	320	321	382	370	250	169	151	138	203	210	263	282	3059
Nadi Airport	293	293	358	185	84	71	48	61	87	95	142	175	1892

(data, in mm, from Fiji Meteorological Service 1981)

Rainfall figures are comparable for both stations for January to March. Extremely high rainfall totals during these months usually coincide with the passage of tropical cyclones. Conversely, it is apparent that Nadi Airport and the west in general experience approximately half the Laucala Bay precipitation from April to December. Similar conditions prevail in north-western Vanua Levu and notably south-eastern Vanua Levu, which lies in the rainshadow of the high mountains of Taveuni (Figure 2.3).

Rainfall variability is high in Fiji, particularly in the dry zone where the average percentage departure from the mean is 20 to 30%. This figure in the wet zone varies from 14 to 20% (Harris 1963).

2.2.2 Cyclones

Fiji lies within latitudes which receive about 12 tropical cyclones per decade, which is the highest frequency of tropical cyclones in the south-west Pacific (McLean 1980). The cyclone season extends from November to April with most cyclones occurring between December and March, although one of the most damaging cyclones in recent years, cyclone "Bebe" passed through the group in October (McLean 1977). Since most cyclones in the south-west Pacific are generated in the region between the Solomon Islands and Vanuatu, and move south-eastwards towards Fiji, it is the north-western parts of Fiji (especially the Yasawas, Mamanucas and western Viti Levu) which experience the most severe winds and highest rainfall totals during the passage of a cyclone.

2.2.3 Temperature

Sea surface temperatures in Fijian waters range from about 25 to 26°C in July to 27 to 28°C in January (Streten and Zillman 1984). As a result average annual temperatures at sea level in Fiji are moderate and consistently lie between 25 and 25.5°C. Variation in temperature throughout Fiji is related to altitude (Fiji Meteorological Service 1982), but there are few inland and elevated recording stations to allow determination of reliable lapse rates. The temperature data available for elevated sites on Viti Levu are compared with data from two sites

Table 2.2: Average Temperatures for Fijian Stations

	J	F	M	A	M	J	J	A	S	O	N	D	YR
Laucala Bay 6 m	26.6	27.0	26.8	26.1	24.9	24.2	23.3	23.4	23.8	24.5	25.3	26.2	25.2
Nadi Airport 16 m	27.1	27.0	26.7	26.2	25.0	24.3	23.5	23.7	24.5	25.2	26.0	26.6	25.5
Colo-i-Suva 235 m	24.5	25.5	25.4	24.8	23.4	22.8	21.9	22.1	21.9	22.6	23.7	24.3	23.7
Nausori Highland 453 m	23.7	23.9	23.9	23.3	22.1	21.4	20.8	20.7	21.5	21.6	22.9	23.8	22.4
Nadarivatu 835 m	21.6	22.1	21.6	21.0	20.0	18.2	18.4	18.7	19.2	20.0	20.7	21.1	20.3
Nadrau 777 m	22.5	22.8	22.4	21.7	20.2	19.5	18.4	18.3	19.2	20.1	21.0	21.7	20.7
Monasavu 808 m	22.1	22.3	22.1	21.3	19.7	18.9	18.0	17.6	18.2	19.3	20.4	21.3	20.1
Koro-O 945 m	21.6	21.5	21.0	20.5	19.2	19.0	17.9	18.2	18.5	19.3	20.3	21.0	19.8

(Data in ^{o}C from Fiji Meteorological Service 1982).

near sea level in Table 2.2 (for location of stations see Figure 2.1). The average lapse rate derived from these figures is 6.4°C 1000 m^{-1}: the figure is slightly higher (6.6°C 1000 m^{-1}) for the "dry" side of Viti Levu and lower (6.2°C 1000 m^{-1}) for the "wet" side. These figures are marginally higher than the lapse rate of 5.5 to 6°C 1000 m^{-1} calculated for the montane tropics in Papua New Guinea (Nix and Kalma 1972; Walker and Flenley 1979).

Seasonal temperature variation is about 3.8°C, with most stations recording highest average monthly temperatures in January or February and lowest temperatures between June and August. Diurnal variation is much higher at all stations, averaging 7.0°C.

2.2.4 Climatic Zones

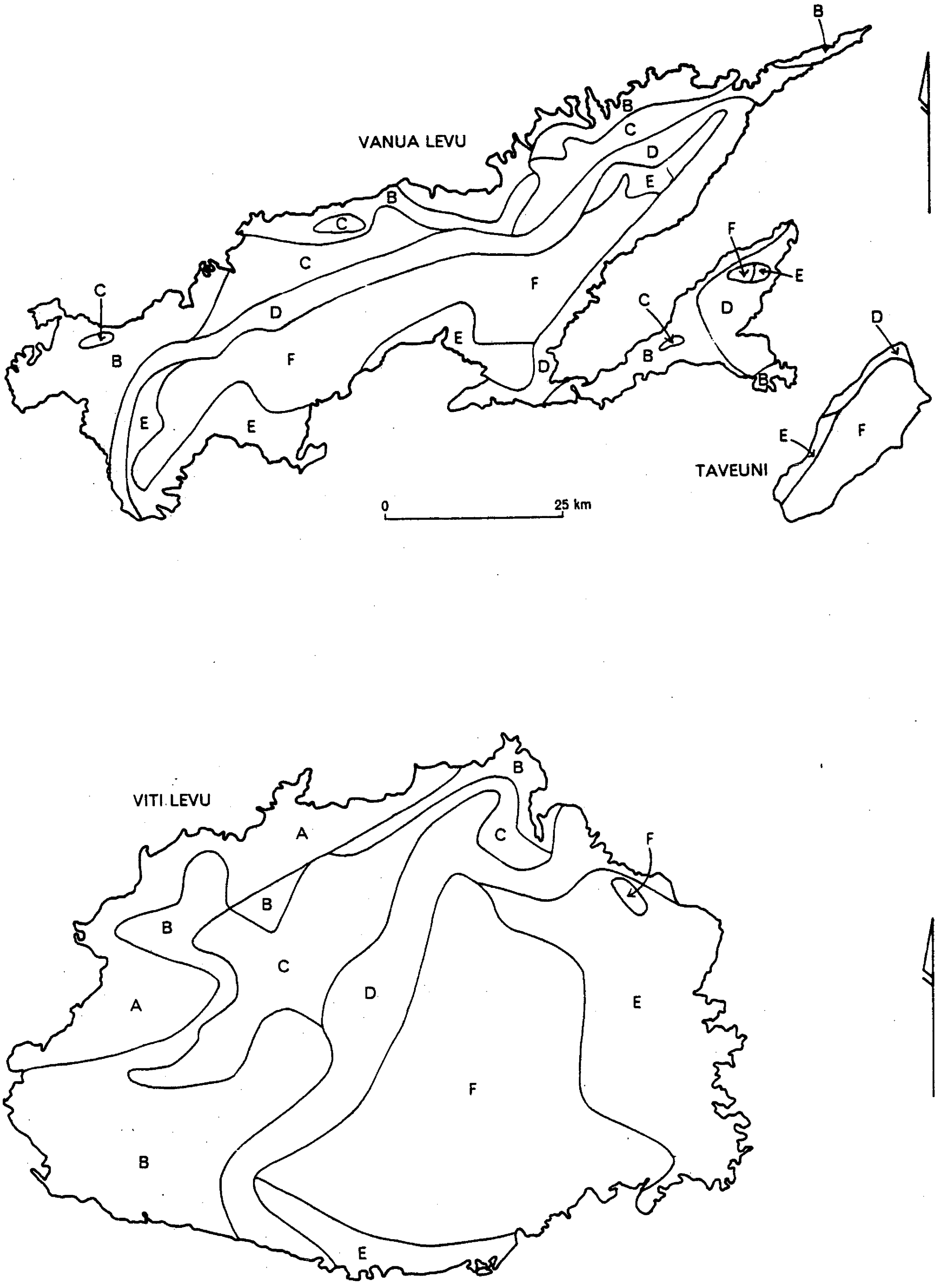
Attempts to divide Fiji into climatic zones have been based upon the spatial distribution of average rainfall and its seasonality. A classification by Harris (1963) divided Fiji into wet and dry zones, defined as those areas which receive greater than 33% or less than 25% of their annual rainfall, respectively, during the months from May to October, that is, the nominal dry season. These two broad zones were subdivided on the amount of rainfall received during the wet and dry seasons and the number of raindays per annum.

Jenkins and Lesslie (in Berry and Howard 1973) used more recent data and divided the islands into six climatic zones, based on average annual rainfall totals and the length and intensity of the dry season. The criteria for separation of these zones is as follows:

Zone F	>3800 mm average rainfall, dry season weak/absent;
Zone E	3050 - 3800 mm average rainfall, dry season weak/1-2 months;
Zone D	2550 - 3300 mm average rainfall, dry season up to 3 months;
Zone C	2550 - 3300 mm average rainfall, but <150 mm per month, dry season long and intense up to 5 months;
Zone B	1650 - 2550 mm average rainfall, dry season long and intense;
Zone A	<1650 mm average rainfall, dry season long and intense.

The distribution of these zones for the main islands of Viti Levu, Vanua Levu and Taveuni is shown on Figure 2.4. This zonation has the advantage of demonstrating the dichotomy between wet and dry climates and emphasising the importance of the seasonal distribution of rainfall.

Figure 2-4: Climatic Zones in Fiji



2.3 Phytogeography

There are about 476 native plant genera in Fiji (van Balgooy 1971) with approximately 2000 species. There is one endemic family, the Degeneriaceae - although this is included in the Winteraceae by some authorities, 11 endemic genera, and about 400 endemic species (Ash and Vodonaivalu in press). This represents 2.3% generic endemism and 20% specific endemism.

There is an attenuation in species diversity moving eastwards into the Pacific islands from New Guinea. Thus diversity in Fiji is greater than that of Tonga and Samoa to the east and, anomalously, greater than that of Vanuatu to the west. Notably 124 plant genera have the eastern boundary of their range in Fiji (van Balgooy 1971; Smith 1979).

Analyses of phytogeographic relationships in the Pacific have grouped Fiji, Tonga, Samoa and Vanuatu together as a Fijian Region or Province (Thorne 1963; Takhtajan 1969; van Balgooy 1971). Smith (1979) expands this grouping to also include Santa Cruz, Rotuma, the Horne and Wallis Islands, and Niue in his Fijian Region and comments that the "...area appears to have substantial phytogeographic cohesion and demonstrates a number of peripheral discontinuities" (Smith 1979: p 30). The tectonic history of the south-west Pacific region, as discussed above, clearly predicts such a close relationship of these island groups.

Fiji assumes an important position in this regional grouping as a source of secondary radiation of taxa (Brownlie 1965; Braithwaite 1975; P.S. Green 1979; Holloway 1979) reflected in the slightly higher degree of endemism in Fiji compared with other islands in the region. This may be a function of the presence of a greater diversity of environments in Fiji, which would lead to a higher degree of speciation, or it may suggest that permanent dry land has been available in Fiji for colonisation for a greater period of time. While Green and Cullen (1973) suggest that dry land was available from the late Miocene, perhaps from 10 million BP, estimates from Vanuatu and Tonga are for a shorter history of possible dry land habitats (Mallick 1975).

Holloway (1979) suggests there is a group of taxa occurring from New Guinea to Fiji, including New Zealand and New Caledonia which probably represents the general flora prevalent in the Melanesian arcs, New Zealand and tropical Australia in the Miocene to early Pliocene. This core group of taxa includes *Agathis*, *Podocarpus*, *Dacrydium*, *Cordyline*, *Ascarina*, *Hedycarya*, *Pittosporum*, *Weinmannia*, *Metrosideros*, *Schefflera* and *Geniostoma*. A large proportion of the remainder of the Fijian flora (ca. 20%) is derived from Malesia (i.e. south-east Asia and Papua New Guinea), and a much smaller proportion (ca. 1.5%) has its centre of origin in

Australia (van Balgooy 1971). Keast (1981) has suggested that the higher proportion of Malesian genera, compared with Australian genera in all Pacific islands' floras is due to the relatively short inter-island distances involved and the fact that many of the plant groups concerned would be pre-adapted to insular conditions.

The genesis of the Fiji Platform as an island arc behind the Indo-Australian and Pacific Plates' boundary suggests that there has never been any direct contact with the landmasses of the Indo-Australian Plate, unlike New Caledonia for example. Neither has there been any direct contact with south-east Asia, which closed with the Indo-Australian Plate near Papua New Guinea only 15 to 20 million years ago (Axelrod and Raven 1982). At this time Fiji and other parts of the Melanesian Borderlands were located well into the Pacific basin (Crook 1981), and the major tectonic movements occurred too early to dramatically influence plant distributions (Chew 1975). Therefore, the flora of the Fijian Region has probably been entirely derived by long-distance dispersal as was suggested by Smith (1979), including the core group of taxa distinguished by Holloway (1979). It is also most likely that the Pacific islands' floras were derived from a recent, rapid spread of taxa as suggested by Carlquist (1967), given the relatively short period during which extensive dryland habitats have been available.

2.4 Vegetation Distributions

While a flora of Fiji is nearing completion (Smith 1979, 1981, 1985) there are few accounts of the general vegetation patterns. Those which do exist are either very brief (e.g. Twyford and Wright 1965; Parham 1972; Berry and Howard 1973; Ash and Vodonaivalu in press), directed towards forest inventory (e.g. Mead 1928; Berry and Howard 1973), or refer to restricted areas in the Fiji Group (e.g. Gibbs 1909; Garnock-Jones 1978; Hassall 1980; Kirkpatrick and Hassall 1981; Kirkpatrick and Hassall 1985; Hassall and Kirkpatrick 1985). The general descriptions imply that vegetation patterns are dominantly a reflection of climatic, edaphic and landform variation within the archipelago, with some modification since the arrival of man. The most marked variation is between the "wet" and "dry" zones of Fiji, with forest and grassland typically dominating the two regions, respectively. These two vegetation types will be dealt with in a general manner below, while more detailed descriptions of the vegetation in the study areas will be presented in the appropriate chapters. Botanical nomenclature in the following is after Smith (1979, 1981, 1985), Parham (1972) and Brownlie (1977), and all species mentioned in the text are listed by family with their authorities in Appendix A.

2.4.1 Forest Vegetation

Forest vegetation covers the southern and eastern parts of the main islands, upland areas in their north and west, and the central parts of some of the smaller islands of the Fiji Group. In the map of vegetation distributions presented below (Figure 2.5, after Ash and Vodonaivalu in press),
the forests have been separated using the UNESCO classification (Fosberg 1967) as follows:

1A1c	tropical evergreen ombrophilous montane forest - occurs in areas of lowland Fiji under high and non-seasonal rainfall;
4A1c	subtropical evergreen montane forest - occurs in areas of lowland Fiji with moderately high, but seasonal rainfall;
1A1e	tropical evergreen ombrophilous cloud forest - occurs in upland areas with high, non-seasonal rainfall;
4A1e	subtropical evergreen ombrophilous cloud forest - occurs in upland areas with moderately high, but seasonal rainfall.

The Fijian forests fall in these categories because of the relatively low stature of the forests (canopy 25 to 35 m compared with 45 to 60 m in Malaysia; Whitmore 1984) and the high proportion of treeferns within them, see Figure 2.6. It is obvious, however, that the term "montane" does not apply here in the usual sense, nor is Fiji "subtropical".

Additional forest types occurring in Fiji include coastal forests and disturbed forests. These will also be described, but are generally restricted in area and cannot be mapped at the scale of Figure 2.5.

1A1c - Tropical evergreen ombrophilous montane forest

Areas under this type of forest receive greater than 2800 mm of rainfall spread evenly throughout the year, and edaphic conditions are generally determined by basalt bedrock. Canopy height in these forests ranges between 15 and 25 m with occasional emergents to 35 m. Species diversity is generally high, without dominant taxa. Characteristic taxa are *Calophyllum*, *Myristica*, *Syzygium*, *Endospermum*, *Canarium*, Sapotaceae, *Parinari*, *Heritiera*, *Elaeocarpus*, and *Agathis*. Most of these taxa occur at higher elevations, but taxa such as *Myristica*, *Endospermum* and *Heritiera* are less abundant.

4A1c - Subtropical evergreen montane forest

The lowland areas of western and northern Viti Levu and Vanua Levu experience lower rainfall (<2800 mm per annum) which has a much more seasonal distribution. These areas have also been subjected to more widespread human disturbance in the past and there has consequently been some degradation of soils (Twyford and Wright 1965). As a result, forest vegetation is generally restricted to

Figure 2-5: Vegetation Distributions in Fiji

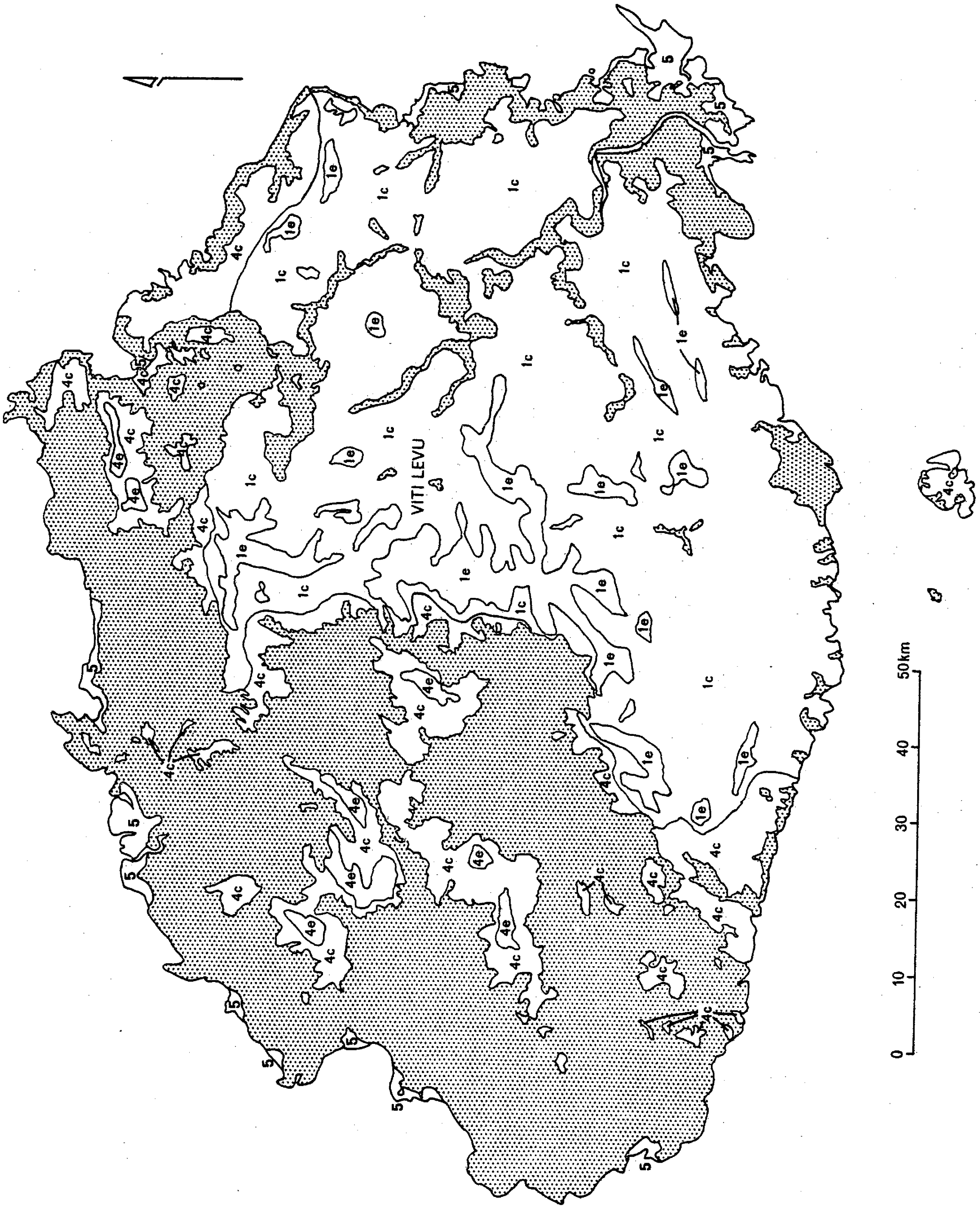


Figure 2.5 cont'd

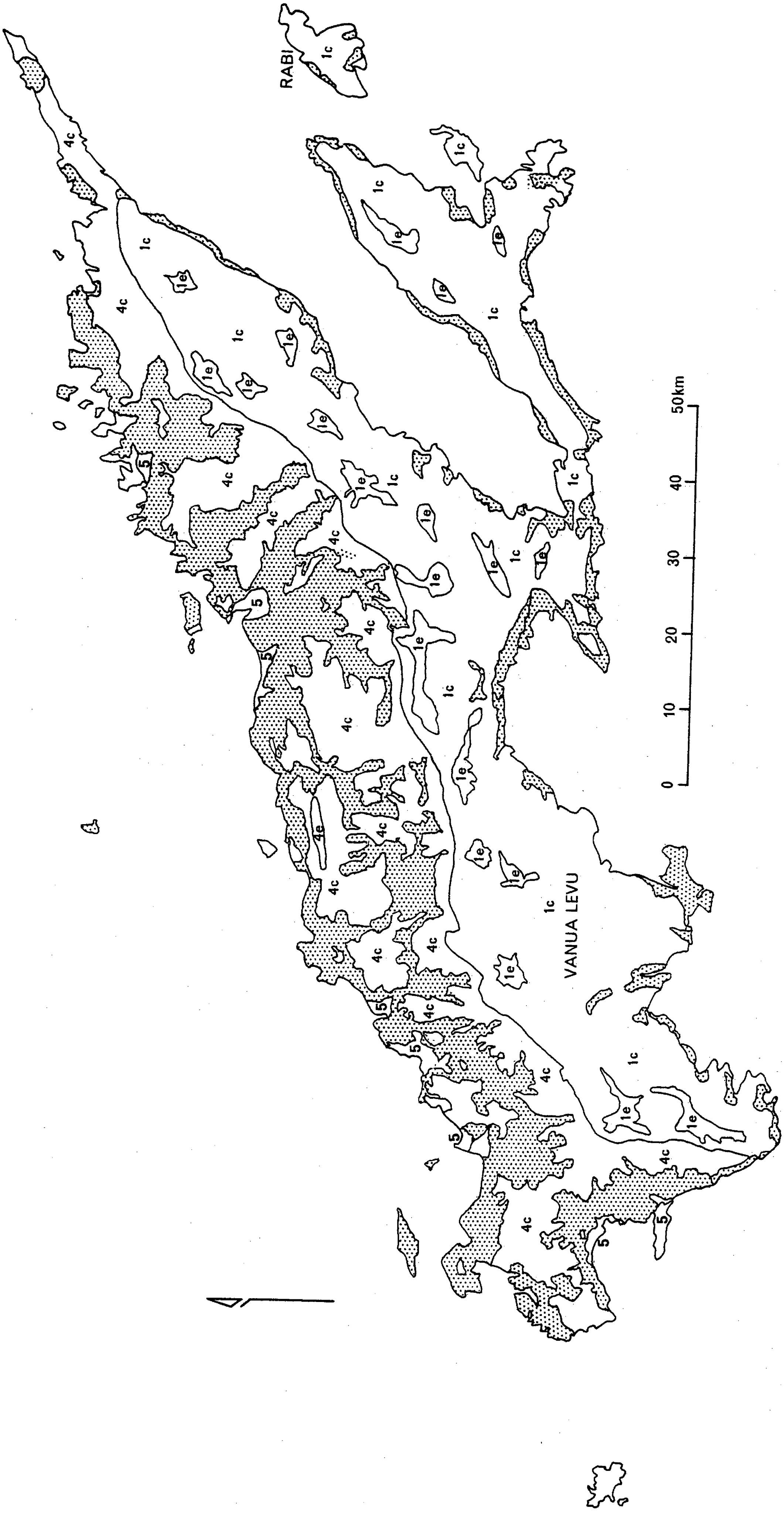
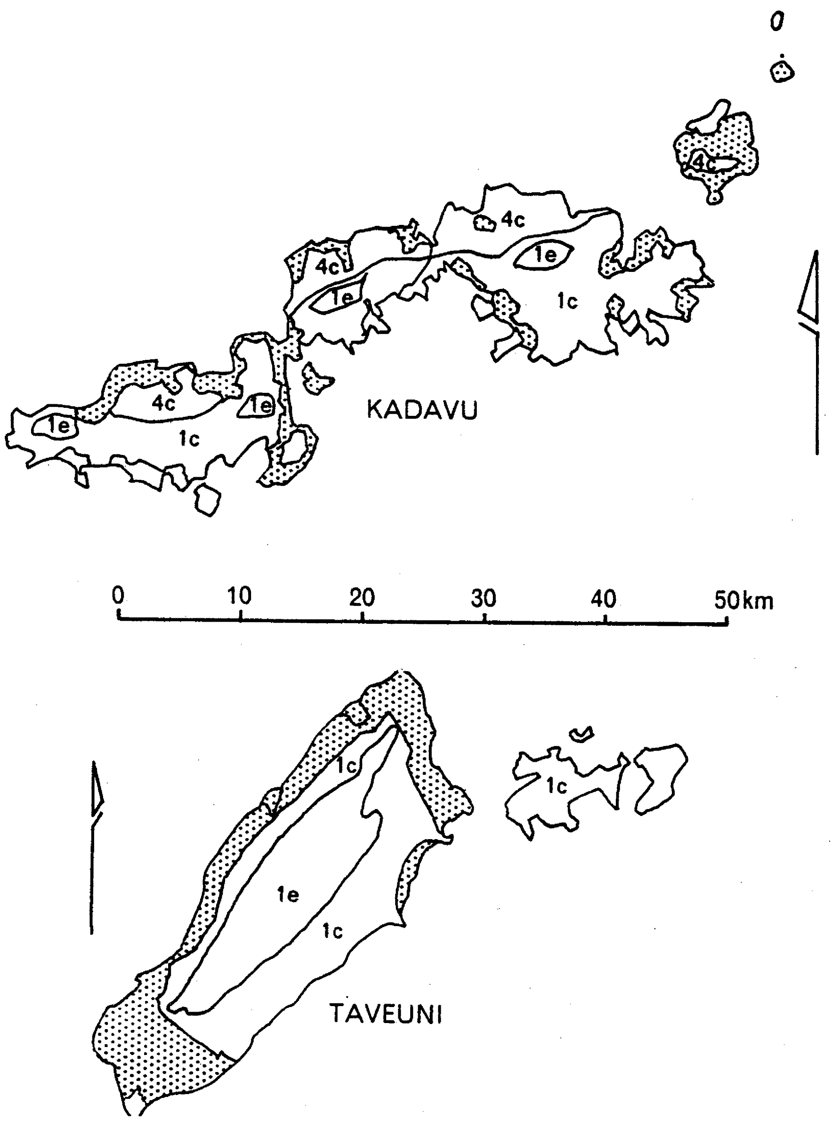


Figure 2.5 cont'd



Key to Forest Types (UNESCO classes)

▨ Not forest covered (includes plantations)

1c = IA1c "Tropical evergreen ombrophilous montane forest"

1e = IA1e "Tropical evergreen ombrophilous cloud forest"

4c = 4A1c "Subtropical evergreen ombrophilous montane forest"

4e = 4A1e "Subtropical evergreen ombrophilous cloud forest"

5 Mangroves

(n.b. 4c & 4e are seasonal variants of 1c & 1e)

Small patches of forest (< 3 sq km) are not shown

Figure 2-6: Forest Vegetation of the "Wet" Zone of Fiji

valleys from which fire has been excluded. Common taxa are *Alphitonia*, *Commersonia*, *Geissois*, and species of Sapindaceae and Meliaceae.

1A1e - Tropical evergreen ombrophilous cloud forest

Areas under this type of forest are characterised by very high non-seasonal rainfall (>4000 mm per annum). The major structural difference in the vegetation with increasing altitude in Fiji is the reduction in the stature of the forest to short-boled trees with wide crowns, and an increase in the number of epiphytes. Generally this change is most marked above 1000 m asl and therefore restricted to inland areas of Viti Levu, Vanua Levu, Taveuni and Kadavu. However, Kirkpatrick and Hassall (1985) note that the same structural types may be observed as low as 400 m asl in mountain ranges close to the coast. They suggest this is a development of the Massenerhebung effect, but discount the hypothesis of Grubb (1971) that it is related to a lack of soil fertility and suggest that shallowness of soil and exposure to strong winds on ridges and crests is a more likely explanation in the Fijian situation. Microclimatic observations on Des Voeux Peak, Taveuni suggest that reduced transpiration rates due to constantly high relative humidity (95 to 99%) may also contribute to the stunted nature of the forests (Ash In prep. a) and certainly contributes to the rich epiphytic flora.

The major floristic difference between the lowland and upland forests is the appearance of the gymnosperms, *Agathis*, *Podocarpus* and *Dacrydium*, as emergents above a broad-leaved lower canopy of *Calophyllum*, *Paphia*, *Freycinetia* and many species of Myrtaceae and Cunoniaceae. On the highest ridge tops the gymnosperms are less common.

4A1e - Subtropical evergreen ombrophilous cloud forest

Upland areas under seasonal rainfall generally support this type of forest. Common taxa are *Gymnostoma*, *Dacrydium* and *Podocarpus*, which often individually form pure stands. Forests of this type occur on isolated upland areas in western Viti Levu (e.g. the Nausori Highlands behind Nadi) and on the western margin of the central upland area of Viti Levu. Smith (1979) suggests that while the generic composition of the forests in both areas is similar, there is differentiation of some important taxa at the species and subspecies level, for example, *Dacrydium nausoriense* (Ash 1986). Smith has postulated that the forests were once continuous across the intervening lowlands and the isolation of the western upland forests from the central Viti Levu forests has been of sufficient duration to allow some speciation. He speculates that environmental conditions in the lowlands have deteriorated from more suitable conditions at an unknown time in the past.

The forested areas are separated at present by extensive tracts of *talasiga* grasslands which are thought to be of anthropogenic origin. Since human occupation in Fiji covers only the past 3500 years or so, and if the western and eastern forests have been separated for long enough for speciation to occur, then it seems possible that the intervening grasslands may pre-date human occupation, or at least they did not support closed forest at the time of arrival of the human population. A light forest is thought to have existed prior to the spread of *talasiga.*

Disturbed forests

Areas of disturbance due to landslides, especially in zones of very high rainfall or on steep volcanic scree slopes, support *Bischofia javanica*, *Dysoxylum* spp. and *Dendrocnide harveyi*. Forested areas which have been subjected to human disturbance in the past (i.e. cleared or burned) characteristically have regrowth dominated by species of Euphorbiaceae and Meliaceae, with *Trichospermum richii*, *Degeneria vitiensis* and *Neonauclea forsteri*. Berry and Howard (1973) identified such areas of secondary forest on aerial photographs and noted their concentration inside the forest edge of the forest grassland boundary suggesting they were sites of former villages or gardens. Villages were possibly located at such sites so that both grassland and forest resources could be exploited (Ward 1965).

Coastal forests

The coastal vegetation in Fiji has been extensively disturbed and in many places replaced by coconut plantations. The small stands of beach forest which remain consist of *Cocos nucifera* with *Intsia bijuga*, *Inocarpus fagiferus*, *Xylocarpus granatum*, *Calophyllum inophyllum*, *Barringtonia racemosa* and *Hibiscus* ***tiliaceus*** (FAO/UNDP 1972a). This is the typical strand flora occurring on tropical coasts around the Pacific.

Mangrove forests are well developed in embayments and estuaries sheltered by reefs on the southern and eastern coasts of the islands and many more small embayments on the leeward coasts of Fiji. There is usually a seaward zone of *Rhizophora stylosa* and associations of *R. samoensis*, *Lumnitzera littorea*, *Brugiera gymnorhiza*, and *Acrostichum aureum* along tidal creeks and at the mangrove/dryland vegetation boundary. Extensive stands of *Pandanus pyriformis* are often present in swamps behind the mangrove fringe (Ash and Ash 1984).

2.4.2 Non-Forest Vegetation

Talasiga

Those areas which receive less than 2800 mm of seasonally distributed rainfall per annum (i.e. the leeward coasts of the main islands, up to 500 m asl and many of the small islands) support grasslands and fernlands which are referred to locally as the *talasiga* or sunburnt lands (see Figure 2.7). The description which follows is largely after Parham (1972).

Talasiga vegetation on Viti Levu largely consists of the introduced grass *Pennisetum polystachyon* and the ferns *Pteridium esculentum* and *Dicranopteris linearis*. The native reed, *Miscanthus floridulus*, the shrubs *Dodonea viscosa*, *Hibbertia lucens*, *Leucopogon cymbulae*, and *Decaspermum vitiense*, and the small trees *Morinda citrifolia*, *Mussaenda raiateensis*, *Acacia richii*, *Syzygium richii* and *Casuarina equisetifolia* occur on slopes of slightly better fertility. On Vanua Levu the *talasiga* may also include *Pandanus odoratissimus* and *Cycas rumphii* f. *seemannii*.

The origin of the *talasiga* lands is open to some discussion. Several authors (Twyford and Wright 1965; Ward 1965; Parham 1972) have speculated that these areas were once covered by light forest, mainly because remnant pockets of forest persist in sheltered valleys. They speculate that the vegetation was reduced to *talasiga* after repeated clearing and burning by man. Subsequent soil degradation, in terms of both fertility and erosion, is also suggested to have occurred. Similar sequences of vegetation clearance and general environmental degradation are recorded throughout islands of the south-west Pacific which support human populations (see Chapter 1.5). On the other hand, Latham (1979, 1983) and Hughes (1985) have suggested the *talasiga* pre-dates the arrival of man and is a relict of much drier periods in the past and simply expanded its range under human influence. This is supported to some extent by Smith's (1979) hypothesis of separation of the western and eastern forests on **taxonomic** grounds.

Freshwater wetland vegetation

The freshwater wetland vegetation of Viti Levu has been described by Ash and Ash (1984). The swamp flora is generally herbaceous and many component taxa have been introduced in the recent past, for example *Rhynchospora corymbosa*, *Pycreus polystachyos*, *Kyllinga polyphylla*, *Paspalum conjugatum*, and *Brachiaria mutica*. Very few indigenous obligate wetland species are evident and include only *Eleocharis dulcis*, *E. ochrostachys*, *Lepironia articulata* and *Sphagnum cuspidatum*. It was further suggested by Ash and Ash (1984) that *E. dulcis* and *L. articulata* may have been aboriginal introductions. However, their abundance in

Figure 2-7: *Talasiga* Vegetation of the "Dry" Zone of Fiji

the more remote swamps of Taveuni, which do not appear to have undergone modification by man (Southern *et al.* in press 1986), suggests that they may well be native species.

The very low proportion of native species in the swamp vegetation and the geomorphology of the swamps on Viti Levu may indicate that they owe their origin to, or have expanded under, the influence of human activities.

2.4.3 Plant Introductions

A large proportion of the Fijian flora is introduced. Most are deliberate introductions of crop plants and ornamentals or inadvertant introductions of weeds since european occupation of the islands. Several other taxa, however, were probably aboriginal introductions. These taxa include the aroid foodplants, *Amorphophallus paeoniifolius*, *Cyrtosperma chamissonis*, *Alocasia macrorrhiza* and *Colocasia esculenta*, the treecrops *Artocarpus altilis* and *Aleurites moluccana.* The endemic species of sago palm, *Metroxylon vitiense*, has also been suggested as an aboriginal introduction (Ash and Ash 1984), and as a closely related variety of the cultivated species (*M. sagu*) in western Melanesia, but its status is unclear at present.

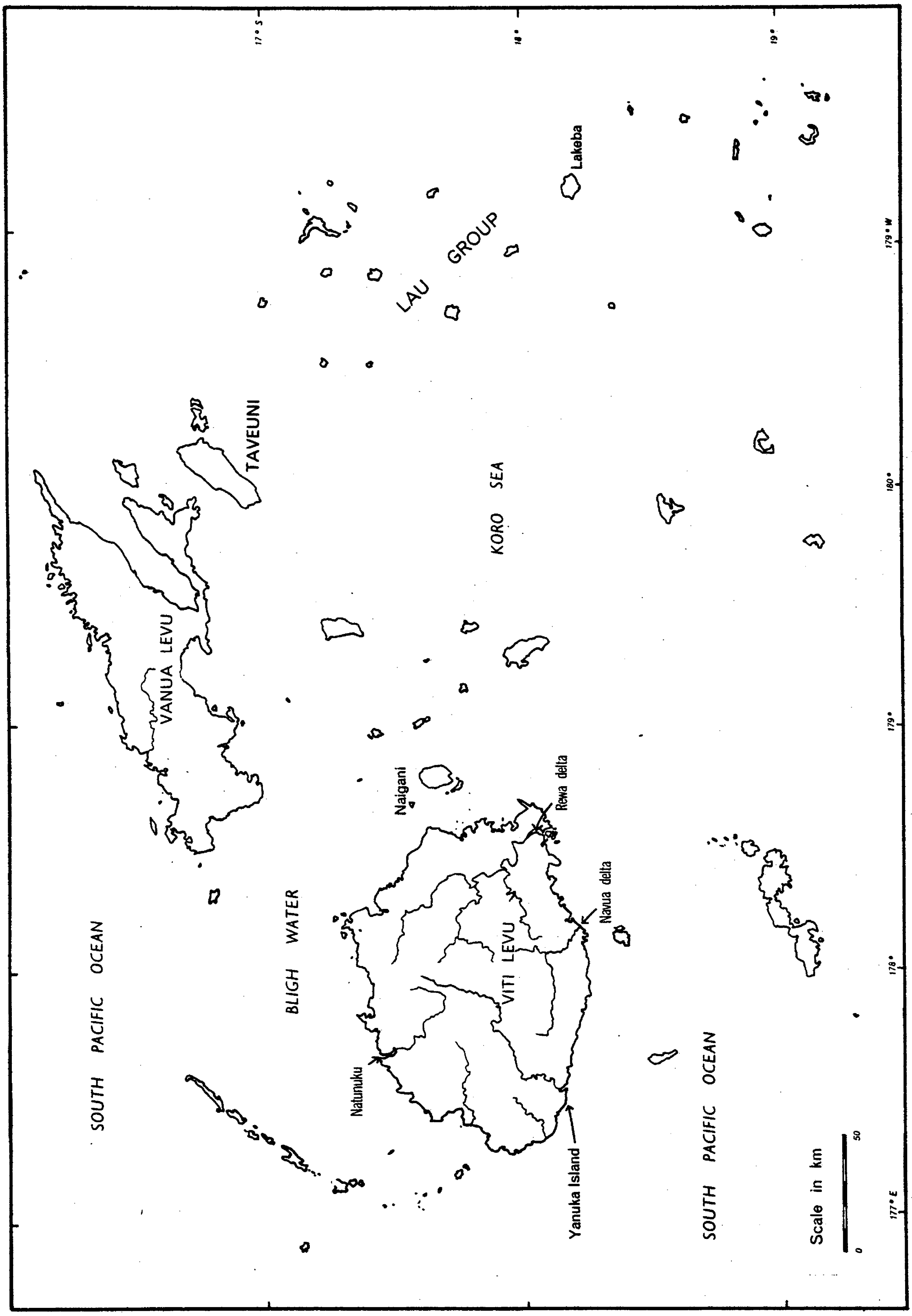
The coconut (*Cocos nucifera*) has been cited as an aboriginal introduction in the south-west Pacific (Dennis and Gunn 1971), but the data of Spriggs (1984b) from Aneityum in Vanuatu strongly indicates that *C. nucifera* was present from about 5400 BP, well before the earliest dates of settlement for Vanuatu or other south-west Pacific islands.

Most of the introductions remain restricted to areas of human disturbance, for example present and former village sites, and rarely penetrate the rainforest. It is notable that in a vegetation survey of Mt Korobaba, just 8 km north-west of the major urban centre of Suva, Kirkpatrick and Hassall (1985) noted only four introduced species out of a total of 310 taxa recorded.

2.5 Human Prehistory and History

The earliest date for human settlement in Fiji is 3240+/-100 BP which comes from an archaeological site at Natunuku on the north coast of Viti Levu, see Figure 2.8 (R.C. Green 1979). The oldest occupation horizons at this site contain abundant remains of Lapita style ceramics. Other sites containing Lapita pottery extend from the Bismarck Archipelago in the west, to Tonga and Samoa in the east; with a range of dates from 4000 to 2500 BP (White and Allen 1980; Kirch 1982c; Spriggs 1984a). Outside the Bismarcks, the oldest reliable dates for Lapita

Figure 2-8: Major Archaeological Sites in Fiji



occur later than 3500 BP (Spriggs 1984a). It has been suggested that the Lapita culture was an indigenous development from earlier cultures in north-west Melanesia (i.e. the Bismarck region; Allen 1984; Gosden and Allen 1984; Spriggs 1984a).

Evidence suggests that an Austronesian language community entered north-west Melanesia from Indonesia. These people probably remained in north-west Melanesia, mixing with the non-Austronesian speakers already present, and at a later date their joint descendents spread to island Melanesia and Polynesia (Spriggs 1984a). The languages spoken east of 136° E fall into the Austronesian sub-group "Oceanic" which seems closely linked with the spread of the Lapita people (Kirch 1979; Pawley 1981; Spriggs 1984a). It is maintained by Pawley (1981) that the Oceanic language group had split from other groups by about 4000 BP, which is consistent with the estimated establishment of Lapita potters in the west by this date and their later settlement as far east as Fiji and Tonga.

There is no evidence to suggest a pre-Lapita population existed in Fiji. The immediate origin of the first Fijian settlers, based on linguistic evidence, was probably from the west. This is substantiated by a classification of Lapita pottery motifs (Anson 1983, quoted in Kay 1984) which indicates a close relationship between Fiji and Vanuatu, and suggests the occupation of Fiji was from Vanuatu to the north-west. From Fiji the Lapita people spread quickly to Tonga and Samoa (by 3210+/-85 BP and 2890+/-80 BP, respectively). Once these populations were established, it is suggested by R.C. Green (1979) that the great inter-island distances to the west effectively severed links with western Lapita communities and the eastern Lapita area of Fiji, Tonga and Samoa developed in isolation. Since closer linguistic ties exist between Fiji and these island groups than with any languages to the west (Davidson 1977), this would seem to have been the pattern of development.

The cultural complex associated with Lapita archaeological sites includes shell and stone adzes, flake tools, scrapers and peelers, sinkers for fishing nets, spear points, grinders and anvils, decorative shell rings and pearl shell discs. The assemblages suggest extensive exploitation of lagoon and barrier reef fish and shellfish (Green 1974). The existence of a terrestrial agricultural base as well is inferred from several lines of archaeological evidence. This includes the location of Lapita settlements near arable land; the apparently large size of the settlements, comparable to present day agricultural communities in the region; the presence of artifacts and structural features (e.g. cooking ovens and storage pits) which are typical of agriculturally based economies; and the presence of pig in the Lapita economy, which has a close relationship with agriculture in ethnographic contexts throughout Oceania (Kirch 1979). Analysis of the associated languages has shown undisputed proto-Austronesian reconstructions of words for all major foodcrops (Pawley and Green 1973).

In Fiji, Hunt (1981) has suggested that abundant remains of possibly adventive and anthropogenically dispersed landsnails in a Lapita site on Yanuca Island (off the south-west coast of Viti Levu, Figure 2.8) by 2980+/-90 BP is supportive evidence of early agriculture. Increased sedimentation rates and the inclusion of carbonised particles from about 2000 BP in swamps on Lakeba in the Lau Group, may indicate large-scale anthropogenic clearing and burning associated with shifting agriculture there (Hughes *et al.* 1979).

A chronological sequence of cultural change since the first settlement of Fiji is largely based upon changes evident in the style and decoration of pottery through time (Green 1963; Frost 1979). Lapita ware with dentate stamped decoration (Sigatoka phase) is replaced by the ceramic tradition of carved paddle-impressed ware at about 2000 BP (Navatu phase). There are two phases (Vuda and Ra) in the third, incised, tradition of Fijian ceramics which dates from about 800 BP. There is some overlap of this style with the earlier Navatu phase.

The changes in ceramic style have been largely explained in terms of successive migrations of people to Fiji, after the original Lapita settlers (Birks 1973; Frost 1979). It is suggested that a wave of immigrants from eastern Melanesia at about 2000 BP brought new ceramic traditions which replaced Lapita ware with impressed ware, but linguistic evidence indicates there was no replacement of language at the same time (Pawley and Green 1973). A further intrusion into Fiji from Melanesia is proposed at 800 BP (Frost 1979) because of a further increment of new ceramic styles and the appearance of fortifications at this time on Taveuni. Frost (1979) suggests this sequence implies the arrival of an immigrant population and subsequent conflict between it and the resident population, probably due to pressures on land resources. On the other hand, Hunt (1981) and Spriggs (1984a) argue strongly for continuity of Fijian culture without accretion from outside sources, based on the ceramic evidence of the Yanuca Island site, where the various ceramic styles in the archaeological assemblages overlap in succession, and linguistic continuity. Hunt (1981) suggests that while immigrants may well have arrived in Fiji, they did not replace or overwhelm the existing population. He explains the appearance of fortifications in terms of sociological and environmental factors within the existing Fijian population.

Evidence from the Navua Delta on Viti Levu suggests that the fortifications there are associated with pottery of an earlier period than Tavueni, and dates of about 1500 BP are expected (G. Irwin, personal communication 1986). This implies the *in situ* development of the fortifications without incursions of immigrant populations.

This position is also taken by Palmer (1969) who has postulated that the form of the fortifications (i.e. a circular ditch with earth causeways to a central village mound, often surrounded by extensive areas of reticulated drainage), especially those in the delta regions of Viti Levu, may have derived directly from local horticultural practises in the production of the staple foodcrops, taro (*Colocasia esculenta*) and via kana, the swamp taro (*Cyrtosperma chamissonis*). Both species require wetland cultivation and flourish in a floodplain situation. They are generally grown on mounds between reticulated ditches, similar in form to those which surround the fortified sites in the deltas. Spriggs (1985) argues for a common date of origin for both forfifications and intensive wetland cultivation.

Palmer (1969) argues that the floodplains offered such a favourable environment for cultivation that the population increased in these areas to an extent which perhaps encouraged the growth of nucleated villages. Population increase may have reached levels in the deltas where pressures on the land and its potential resources resulted in conflict for possession of land. Certainly at the time of european contact (ca. A.D. 1800) the various villages had aligned into political states under the leadership of powerful chiefs. Rivalry between these chiefdoms for valuable agricultural land resulted in the often bloody battles and cannibal activities noted by early european observers (quoted in Clunie 1977). A maze of water-filled ditches undoubtedly provided an effective defense against hostile groups.

Very little is known of the inland peoples of Fiji, the "Kai Colo" or mountain people, in these early times, but the coastal tribes generally feared them and claimed that their feats of violence were greater than anything experienced in the coastal wars (Scarr 1984). Upland fortifications were also common and of a similar ring and ditch form, usually modified to suit the local topography and to take advantage of natural defensible positions (Palmer 1969; Frost 1974). Palmer (1969) suggests that the interior of the main islands was first sparsely populated by people practising shifting agriculture, and that the fortifications came later, probably after their development in the lowlands, but there are no dates for initial settlement of inland areas. Linguistic evidence (Pawley and Green 1973) suggests the central plateau region of Viti Levu forms a natural divide between the two main dialects of Fiji. The split in languages probably occurred after a long period of more or less unified language development, and after a sizeable inland population had built up on Viti Levu.

European contact with Fiji dates from 1643 when Tasman passed through the islands, followed in 1774 by Cook and in 1789 by Bligh. Contact was more firmly established by 1801 when extensive stands of sandalwood were reported on Vanua Levu and a long period of resource exploitation was initiated. By 1814 these stands were so depleted that trading was no longer viable and interest was transferred to a trade in Beche-de-mer (Scarr 1984).

Tribal hostilities were violent during these early years of european settlement and were exacerbated by the introduction of firearms, which ultimately facilitated the rise in power of the tiny islet of Bau, off the south-east coast of Viti Levu, to a dominant position in the islands. There was almost constant war in the Rewa Delta region during the early nineteenth century as Baüans decimated croplands, villages and the population (Parry 1977). An even greater cause of death amongst Fijians, however, was disease, introduced by the european settlers. The most virulent measles epidemic killed an estimated 25% of the population in less than four months in 1875 (Ward 1965). The number of people living in the deltas was severely reduced, villages were deserted and food gardens abandoned and overgrown (Parry 1977).

During the first half of the nineteenth century many europeans settled in Fiji and began operating sugar and coconut plantations on the coastal plains of the main islands and some of the smaller islands. It is likely that the planters obtained possession of the land illegally, but by 1871 when Cakobau, the chief of Bau, declared himself king of Fiji, they were claiming the need for British protection as a colony. By 1874, Fiji was ceded to Britain and a colonial administration installed.

During the period of British rule the sugar industry achieved pre-eminence and became concentrated on large tracts of **alienated** land on the leeward coasts of Viti Levu and Vanua Levu. From 1879 much of the labour force was indentured from India. Nearly 61 000 labourers arrived until 1916 when the scheme was abolished (Scarr 1984). While many returned to India at the end of their period of indenture, more than 50% of the present population of Fiji is Indian.

The sugar industry remains important in Fiji, but coconut plantations, while still extensive on southern Vanua Levu and Taveuni, are gradually being replaced by other agricultural activities, especially since independence in 1970. Most of the inland, forested areas, however, remained virtually untouched until intensive forestry activities became common during the present century.

CHAPTER 3

MODERN POLLEN RAIN IN FIJI

Investigation of modern pollen rain is aimed at determining the production and dispersal of pollen and its relationship with the modern vegetation. In this way, modern pollen assemblages may provide analogues for fossil assemblages and aid interpretation of them in environmental terms. Most pollen analytical studies include a study of the modern pollen rain of the surrounding vegetation. While each study reveals different patterns, it is possible to extract some general principles for tropical pollen rain before discussing the specific case of Fiji.

The classic model for pollen transfer was derived from temperate deciduous forest regions (Tauber 1965, 1967). In this model Tauber identified the following components of the pollen rain to a basin:

1. a trunkspace component carried through and within the forest;
2. pollen carried by wind above the canopy;
3. pollen which is rained out from the atmosphere;
4. pollen which is filtered out in the trunkspace and later refloated during periods of runoff to the sedimentary basin.

Kershaw and Hyland (1975) set out to test this model in a tropical setting at Lake Euramoo on the Atherton Tableland in north-east Queensland. They concluded that in a rainforest situation, where the vegetation has a dense and complex structure, high diversity with mainly entomophilous (insect-pollinated) species, an absence of strong winds within the forest, continuous rainfall or wet and dry seasons, and little if any annual deciduousness, Tauber's model of pollen transfer had to be modified. As Flenley (1973) pointed out, there is little opportunity for trunkspace movement of pollen in rainforest, and that traps situated outside the forest (e.g. the fossil samples from a lake basin) would receive little or no pollen from this source. Kershaw and Hyland (1975) comment that while lakes of small dimensions in tropical forest situations would be unlikely to be influenced by above canopy winds and therefore unlikely to trap that component of the pollen rain, any pollen released above the canopy could be washed out almost immediately. This would presumably occur before regional mixing of the pollen had taken place and thus be representative only of the local forest type. However, the results from Lake Euramoo indicate that the pollen fallout is regionally derived, mostly from canopy trees, with little input from rained-out pollen or understorey taxa. Grindrod (1979) also comments from his work at Lake Eacham, again on the Atherton Tableland, that there is a consistent input of taxa derived from regional sources. Kershaw and Hyland (1975) conclude that Lake Euramoo (and Lake Eacham, which is in a similar situation) represents a marginal rainforest environment, and the relationships may not apply to true rainforest.

Flenley (1979a) reviewed the available information on modern tropical pollen rain and came to the following conclusions.

1. In montane areas there is apparently a net upward transfer of pollen, such that forest pollen types are frequently found in samples from above the forest limit. Pollen transfer in the opposite direction is apparently extremely rare. This may be due partly to the greater pollen production in the forested areas, but also to meteorological factors, for example the prevalence of up-valley winds.

2. Pollen rain in the lowlands is characterised by extremely high diversity. Identifications may be made generally only to genus or family level, such that ecological interpretation is difficult.

3. There is a tendency for dominance by pollen of local trees in lowland rainforest pollen samples, possibly because of low wind velocities within the forest which restrict the lateral movement of pollen. This is less marked in montane forest situations because of better development of winds.

4. The magnitude of the pollen rain in the tropics (i.e. pollen influx, grains $cm^{-2}. yr^{-1}$) is of a similar order as at least some temperate regions.

These conclusions were derived from palynological research in the tropics of Africa, South America, and Indo-Malaysia .

The task of matching the pollen rain to identifiable vegetation types is exacerbated in a rainforest situation. The vegetation tends to vary continuously in the absence of sharp topographic or edaphic boundaries. There is rarely a single dominant species, or even a few dominant species (as is the case with most temperate forests), rather there is a large number of evenly distributed species, so that many pollen types must be identified. Unfortunately this is often only possible to generic or family level and in many cases taxa which characterise the vegetation may not be present in the pollen rain; both of which make ecological interpretations of pollen assemblages difficult.

The task may be difficult, but it has not proved impossible. In north-east

Queensland rainforests, Kershaw (1973) analysed surface samples from rainforest, subjected the pollen spectra to classification and ordination programs and compared these results with classifications and ordinations of the floristic and environmental data from the rainforest sites. He concluded that while variation was along a continuum, the pollen spectra could be placed within an environmental framework and interpreted to a large extent in environmental terms.

An extensive program of pollen trapping and surface sampling on Mt Wilhelm, Papua New Guinea (Hope 1976), also resulted in the conclusion that all vegetation communities present had distinctive pollen assemblages. However, the situation in tropical montane environments is probably inherently less complex than lowland environments (Flenley 1973).

Morley (1982a) concluded from his analysis of modern pollen rain in the Kerinci area of Sumatra that the major forest types, which were altitudinally differentiated, had characteristic pollen assemblages. He also noted, however, that the net upward movement of pollen described by Flenley (1979a) was not apparent in the Kerinci area; possibly because meteorological conditions and a tendency for the higher altitude vegetation to have higher pollen productivity mitigated against upward pollen movement.

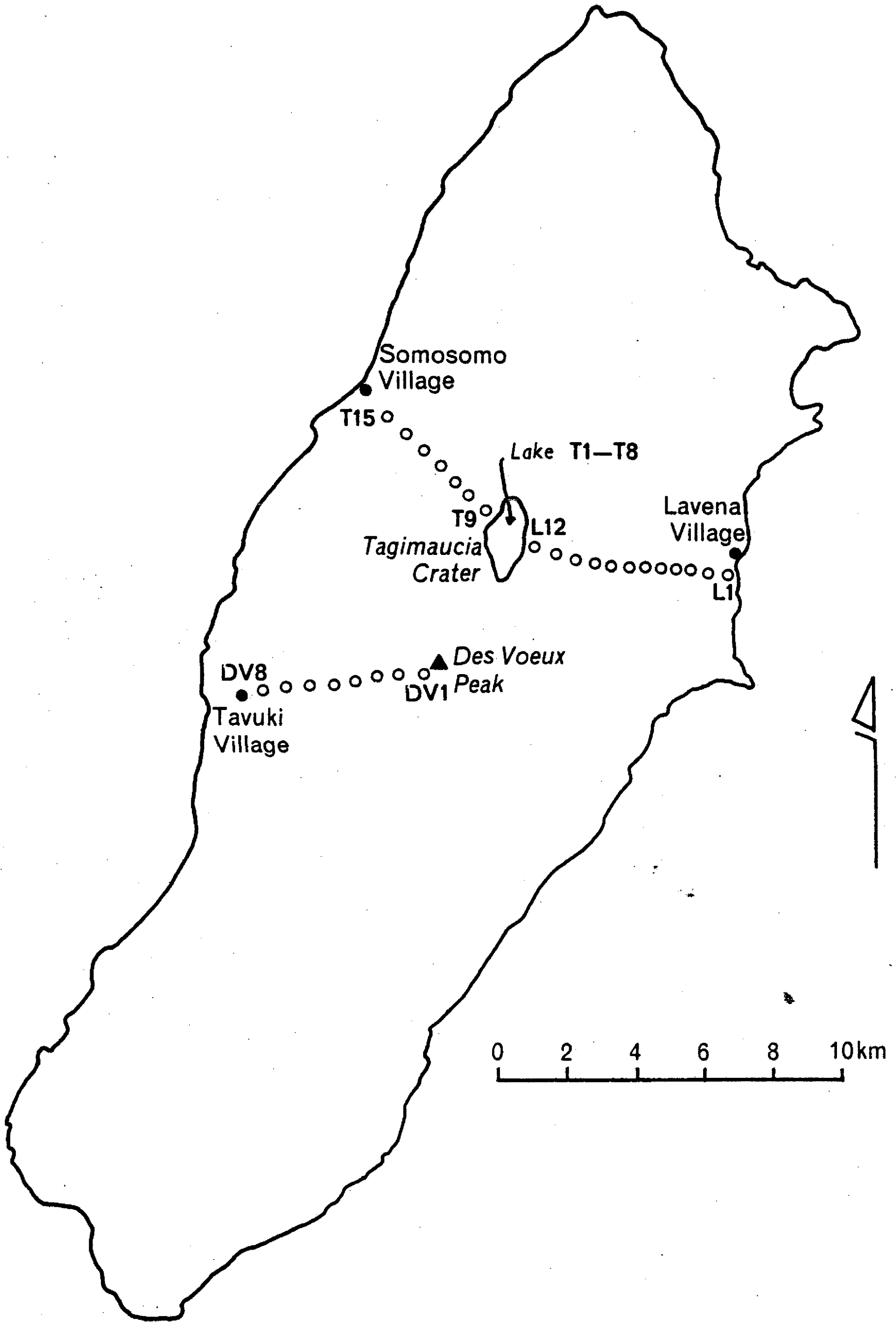
The pollen sites investigated in Fiji fall into two geographical groups. Firstly, Lake Tagimaucia, Nadrau Swamp and Wainisavulevu Creek are located within upland and forested areas; and secondly, the Rewa and Navua Delta sites are from lowland, coastal areas. The pollen rain differs between the two and they are therefore treated separately. A set of surface pollen samples was collected from forests throughout Taveuni and the Wainisavulevu and Mt Tomaniivi ridges in central Viti Levu. Surface samples were also collected from a range of coastal environments within the Navua Delta and near Lautoka in north-western Viti Levu.

3.1 Forest Pollen Rain

3.1.1 Methods

Moss polsters and surface samples were collected from two transects on Taveuni. Firstly, from Lavena Village in the east, to the central ridge of Taveuni (samples L1 to L12) and the Lake Tagimaucia basin (samples Lake, T1 to T8) down to Somosomo Village in the west (samples T9 to T15). A second transect of samples passed from Des Voeux Peak to Tavuki Village near the coast in the west (samples DV1 to DV8), see Figure 3.1. This procedure was directed towards sampling the range of forests and environments presently occurring on Taveuni and

Figure 3-1: Approximate Location of Surface Sample Sites on Taveuni



the transects effectively cover the wet lowland, wet and cool montane, swamp, drier montane and drier lowland environments of the island.

Generally high and non-seasonal rainfall and highly fertile soils prevail over most of Taveuni, so the vegetation tends to vary imperceptibly in terms of species content, but more obviously in terms of forest structure. The forests are generally tall in the lowlands and with increasing altitude (and rainfall) there is obvious stunting of the trees, and epiphytic ferns, mosses and lichens become abundant. The nature of forest structure may have an effect on the pollen rain, in that filtering of pollen (sensu Tauber 1967) may be more or less likely to occur, depending on whether the forest has an open or closed understorey. The data from Mt Wilhelm indicate that no filtration occurs in very wet areas (Hope 1976). The forest edge in rainforest situations tends to present an impenetrable barrier and it is likely that little pollen will move from the understorey to an external depositional basin except by water.

A more extensive range of environments was therefore sought elsewhere in Fiji. A further two transects of moss polster and surface samples were collected from the Mt Tomaniivi and Wainisavulevu Ridges (samples Tom1 to Tom5 and W1 to W7) in central Viti Levu, see Figure 3.2. These surface samples were derived from relatively drier and more elevated environments than presently exist in upland Taveuni. The vegetation, location and characteristics of the modern pollen sites are described on Table 3.1.

The transects were divided into approximately 150 to 200 m altitudinal intervals. Since lateral movement of pollen in rainforest situations is rare and surface pollen spectra may be dominated by a single species growing nearby, the forest moss polster samples were collected as subsamples along each of the altitudinal intervals and then bulked together. It was hoped that the samples would then give a representative pollen spectrum for each altitudinal range. Samples from the Lake Tagimaucia basin were surface samples collected from each of the vegetation types identified by Southern *et al.* (in press 1986) (and described more fully in Chapter 4.2) and one from the lake base.

The bulk samples were mixed in the laboratory and a 1 cm^3 subsample was extracted for pollen analysis. Samples were prepared using the following method.

1. Samples were placed in large plastic centrifuge tubes with 15 ml of a 10% solution of potassium hydroxide, then suspended in a boiling water bath for 20 minutes and frequently stirred. This physically disperses the sample and breaks down the cellulose. Samples were then passed through a mesh seive to remove large particles, balanced with distilled water, centrifuged and decanted twice.

Figure 3-2: Approximate Location of Surface Sample Sites on Viti Levu

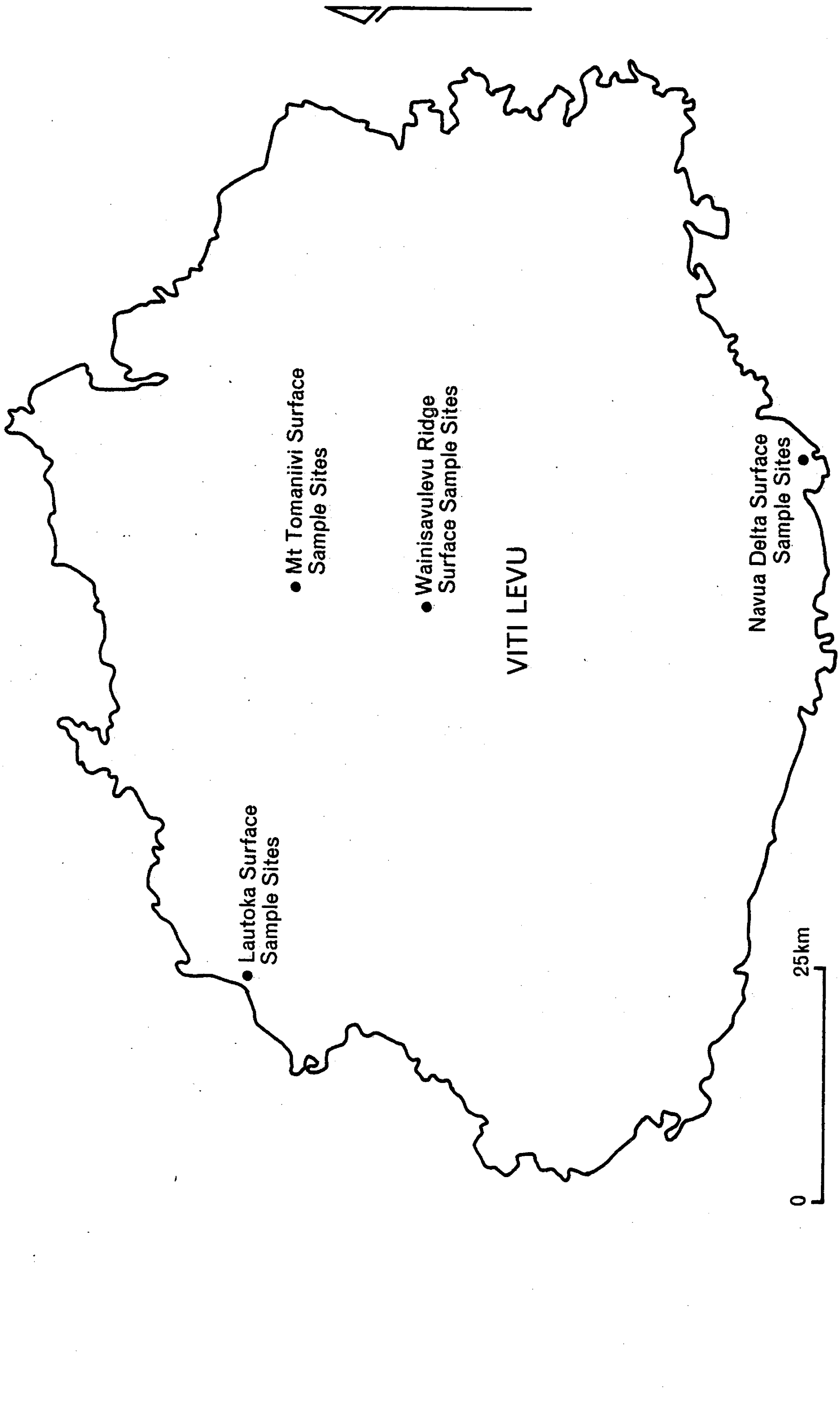


Table 3.1: Site Characteristics of Forest Surface Samples

Site	Av. Alt. (m)	Site Characteristics
L1	6	Littoral forest dominated by *Cocos nucifera*, with *Intsia bijuga*, *Inocarpus fagiferus* and *Barringtonia racemosa*.
L2	60	Tropical evergreen ombrophilous montane forest with *Agathis*, *Endosperm*, *Hernandia*, *Myristica*, *Syzygium*, *Palaquium*, *Canarium*, *Parinari*, and *Heritiera*.
L3	100	As above
L4	150	As above
L5	200	As above
L6	280	As above
L7	400	As above
L8	500	As above
L9	600	As above
L10	700	As above
L11	820	Tropical evergreen ombrophilous cloud forest with *Cyathea*, *Cryptocarya*, *Neubergia*, *Podocarpus*,
L12	860	As above with *Clinostigma*, *Macaranga*, *Metrosideros*, *Podocarpus*, *Rapanea*, *Sterculia*.
Lake	820	Open water with sparse phytoplankton community.
T1	820	Edge of swamp, near forested slopes with *Lepironia articulata*, *Clinostigma*, *Freycinetia*, *Metrosideros* and mosses.
T2	820	*Lepironia* swamp, mainly *Lepironia* and *Lepidosperma*.
T3	820	*Sphagnum* hummocks with *Sphagnum*, *Dicranopteris*, *Metrosideros*, *Scaevola*, *Weinmannia*.
T4	850	Forest margin near swamp with *Cyathea*, *Calophyllum*, *Heliconia*, *Geniostoma*, *Macaranga*, *Maesa*.
T5	820	Sparse *Lepironia* swamp with *Lepironia* and *Lepidosperma*.
T6	820	Productive *Lepironia* swamp with *Lepironia*, *Lycopodium* and *Freycinetia*.

Table 3.1 cont'd

Site	Av. Alt. (m)	Site Characteristics
T7	820	*Eleocharis* swamp in standing water with *Eleocharis*, *Polygonum*, and *Mikania micrantha*.
T8	820	Tropical evergreen ombrophilous cloud forest with *Podocarpus neriifolius*, *Calophyllum vitiense*, *Cryptocarya hornei*, *Citronella*, *Litsea* and *Neubergia alata*.
T9	850	Tropical evergreen ombrophilous cloud forest with *Macaranga harveyana*, *Clinostigma exorhiza*, *Cyathea alta*, *Calophyllum vitiense*, *Dysoxylum richii* and *Syzygium*.
T10	830	As above.
T11	850	As above.
T12	550	Tropical evergreen ombrophilous montane forest with *Macaranga harveyana*, *Calophyllum vitiense*, *Dysoxulum richii* and *Myristica castaneifolia*.
T13	370	As above.
T14	300	As above.
T15	180	Edge of subsistence gardens with *Ficus*, *Cyathea*, *Cocos*, *Endospermum macrophyllum* and *Myristica castaneifolia*.
DV1	1200	Cleared area at the summit of Des Voeux Peak with *Ficus*, *Spiraeanthemum*, *Scaevola*, *Pipturus*, *Gleichenia*, *Blechnum* and sedges in the surrounding vegetation.
DV2	1100	Summit ridge with forest composed of similar species as above.
DV3	1150	Tropical evergreen ombrophilous cloud forest on the ridge with many species of Cunoniaceae, *Ficus vitiensis* and *Astronidium*.
DV4	1140	Forest similar to above but with much climbing *Freycinetia*.
DV5	1075	Tropical evergreen ombrophilous cloud forest on very steep scoria slopes with abundant *Clinostigma*, *Spiraeanthemum* and *Macaranga*.
DV6	1050	Forest on steep scoria slopes as above with *Clinostigma*, *Dysoxylum*, *Syzygium* and *Neubergia*.
DV7	775	Tropical evergreen ombrophilous cloud forest on basalt with *Dysoxylum*, *Endosperm*, *Alphitonia* and *Palaquium*.
DV8	460	Partly cleared tropical evergreen ombrophilous montane forest with abundant *Cyathea*, *Dysoxylum*, *Myristica* and *Planchonella*.

Table 3.1 cont'd

Site	Av. Alt. (m)	Site Characteristics
Tom1	1323	Tropical evergreen ombrophilous cloud forest with abundant *Paphia*, *Calophyllum*, *Freycinetia* and species of Myrtaceae and Cunoniaceae.
Tom2	1150	As above but with emergent *Podocarpus*.
Tom3	1000	Tropical evergreen ombrophilous cloud forest with *Agathis* emergent over *Calophyllum*, *Metrosideros* and *Parinari*.
Tom4	850	Subtropical evergreen ombrophilous montane forest with *Agathis* again emergent over *Calophyllum*, *Myristica*, *Heritiera*, *Parinari*, *Dacrydium*, and Myrtaceae.
Tom5	730	Forest as above but with abundant *Dacrydium*, *Gymnostoma*, *Endospermum* and *Myristica*.
W1	900	Subropical evergreen ombrophilous montane forest with *Clinostigma* and *Cyathea* emergent over *Scaevola*, *Omalanthus*. *Metrosideros* and *Calophyllum*.
W2	990	Subtropical evergreen ombrophilous montane forest with *Agathis* and *Dacrydium* emergent over *Endospermum*, *Palaquium* and *Canarium*.
W3	990	Tropical evergreen ombrophilous montane forest with *Agathis* emergent over forest with *Calophyllum*, *Endospermum*, *Metrosideros* and *Parinari*.
W4	990	As above.
W5	1060	Tropical evergreen ombrophilous cloud forest with abundant *Dacrydium*, *Dacrycarpus* and *Palaquium*.
W6	1060	As above.
W7	918	Tropical evergreen ombrophilous cloud forest with *Podocarpus*, *Dacrydium*, *Physokentia*, *Cyathea*, *Freycinetia* and *Pandanus*.

2. Approximately 10 ml 70% hydrofluoric acid was added to each sample and left for 24 hours. This effectively removes silicates. The samples were then balanced with 5% hydrochloric acid, centrifuged, decanted, washed with distilled water, and centrifuged and decanted again.

3. The standard acetolysis technique (Faegri and Iversen 1974) was then applied to remove humic acids and much of the remaining organic material. This involved washing in 30% acetic acid and glacial acetic acid, then boiling in a 9:1 mixture of acetic anhydride and concentrated sulphuric acid for 1 minute. Samples were then centrifuged, the supernatant decanted, balanced with glacial acetic acid, 30% acetic acid and finally distilled water.

4. Samples were finally treated with an alcohol series (80% and absolute alcohol followed by tertiary butyl acohol) for dehydration prior to mixing with silicon oil (Ak 2000) for placement on microscope slides. The volume of silicon oil to the remaining samples was 4:1.

Pollen counts proceeded until 200 dryland pollen grains had been recorded, except in samples where the pollen concentrations were too low to allow a full count, and in samples T5, T6, T7 and DV2 where there was too little pollen to allow a count at all. The pollen and spore taxa throughout this study were identified using a reference collection of modern pollen and spore types prepared from material collected from the herbarium at the University of the South Pacific (SUVA), or collected from flowering material near the field sites. These samples were prepared in the laboratories of the Department of Biogeography and Geomorphology, Research School of Pacific Studies, Australian National University, using the technique outlined above, but omitting the hydrofluoric acid step. A set of reference slides is lodged in the Biogeography and Geomorphology Department.

3.1.2 Results

The forest surface sample pollen counts are presented on Figure 3.3 as percentages of a pollen sum consisting of all dryland pollen types.

This pollen sum was chosen to allow assessment of the representation of forest taxa since this will be of primary importance for interpreting the fossil pollen diagrams. Fern spores and swamp taxa have been excluded from the sum as they often have very high and erratic representation in the counts and would distort the percentages of other taxa. The percentages were calculated from the raw scores, and the original diagram was plotted by the program POLLEN on the A.N.U. Univac computer. All percentage pollen diagrams in this thesis were prepared in this way. Only common taxa are presented on the pollen diagram, while the full raw pollen counts (and all subsequent modern and fossil pollen counts in this thesis) are contained in Appendix B. The notations of Benninghoff and Kapp (1962) have been used on this and all subsequent pollen diagrams to indicate the degree of certainty of pollen identifications.

Figure 3-3: Forest Surface Pollen Spectra

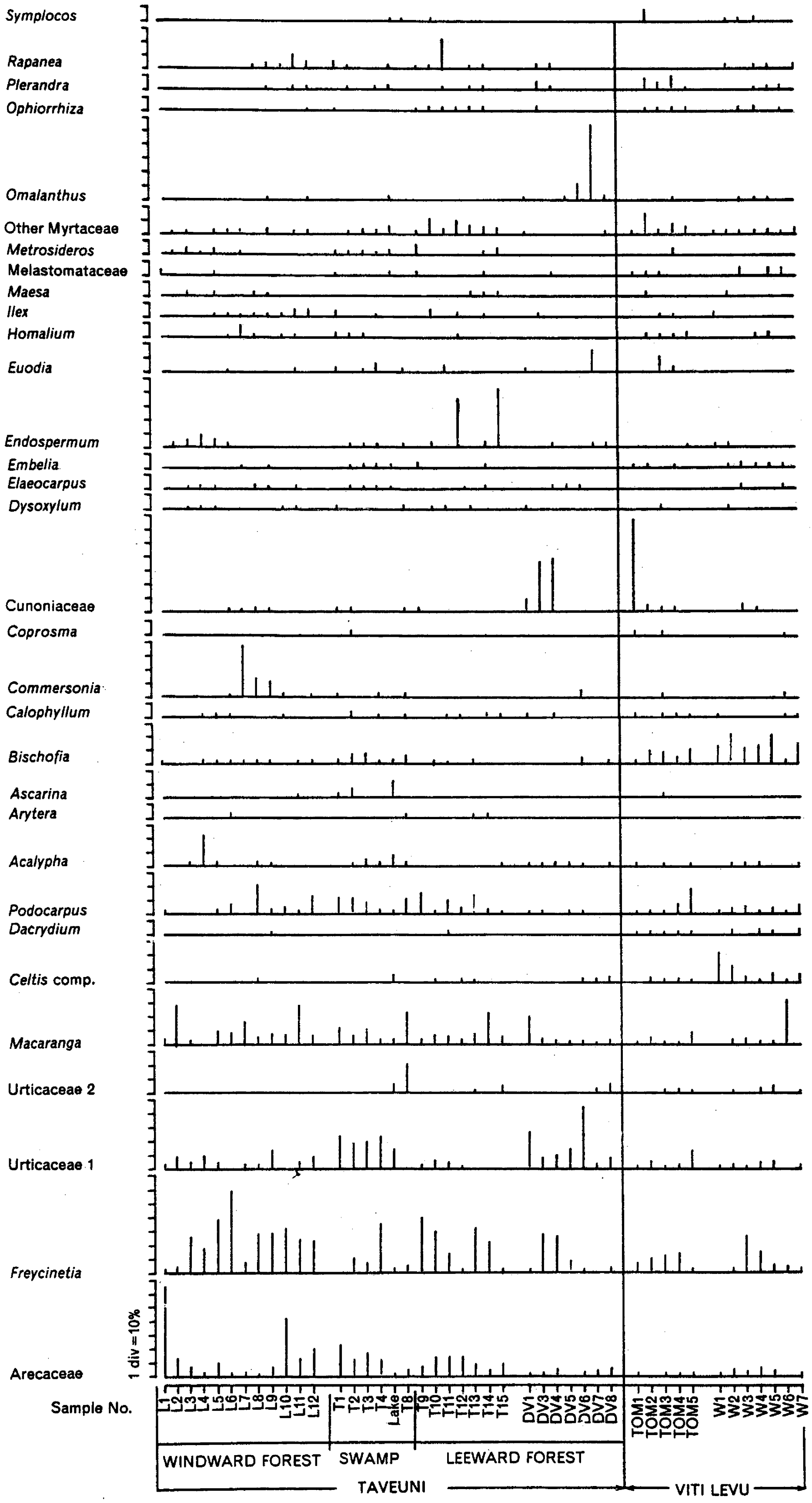
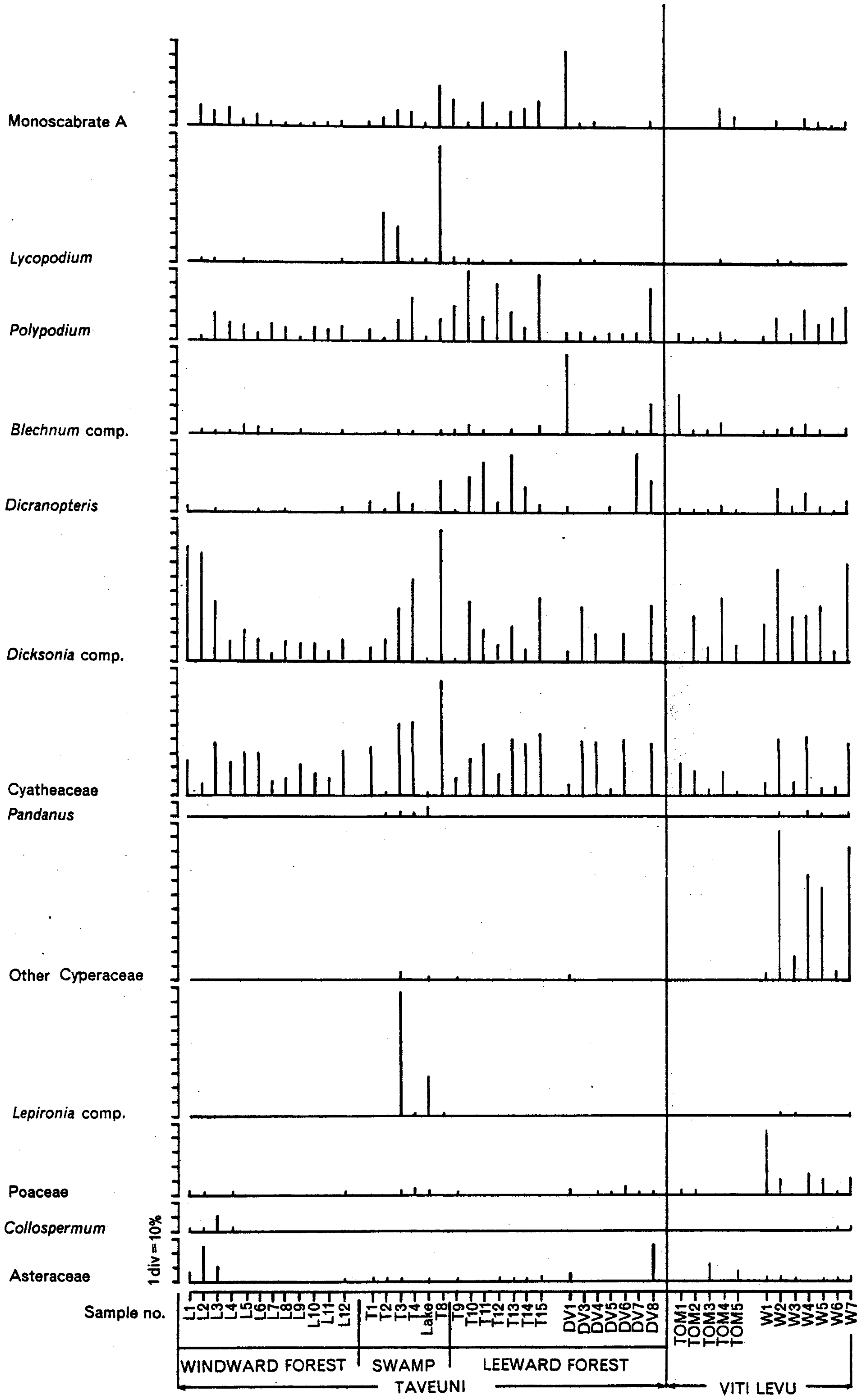


Figure 3-3 cont'd



There is a great degree of variation in the forest surface pollen samples and each group of samples (i.e. windward Taveuni, Tagimaucia basin, leeward Taveuni, Mt Tomaniivi, and Wainisavulevu Ridge) will be described separately.

1. The windward forest surface samples are dominated by pollen of the Arecaeae (especially near the coast and on the ridges above the lake - L1 to L5 and L10 to L12), *Freycinetia* and *Podocarpus* (which increase with altitude), *Macaranga*, Cyatheaceae, and *Polypodium*. At low elevations *Endospermum*, *Acalypha*, Asteraceae (tubuliflorae), *Dicksonia* comp. and *Blechnum* comp. are common. At middle to high elevations *Commersonia*, *Elaeocarpus*, *Homalium*, *Ilex*, Myrtaceae and *Rapanea* are more common.

2. The surface samples from the Tagimaucia basin have high values for Arecaceae, *Freycinetia*, Urticaceae 1, *Macaranga*, *Podocarpus*, *Lepironia* comp. and the ferns Cyatheaceae, *Dicranopteris*, *Polypodium* and *Lycopodium*. Urticaceae 2, *Acalypha*, *Ascarina*, *Bischofia*, Poaceae and *Pandanus* have lower, but consistent representation in these samples.

3. The leeward forest surface samples on Taveuni are in two groups, T9 to T15 and DV1 to DV8. The first is dominated by Arecaceae, *Freycinetia*, *Macaranga*, *Podocarpus*, Cyatheaceae, *Dicksonia* comp., *Dicranopteris* and *Polypodium*. At higher elevations Myrtaceae is slightly more common; at lower elevations *Endospermum* has its highest representation in all the surface samples. The Des Voeux Peak samples cover a greater range of elevations. The highest sites are characterised by high values for *Freycinetia*, Urticaceae 1, *Macaranga* and Cunoniaceae. At lower elevations the common pollen taxa are *Celtis* comp., *Omalanthus* and *Dicranopteris*.

4. The Mt Tomaniivi samples (Tom1 to Tom5) extend from 1323 m to 730 m. At the highest elevations Cunoniaceae is very common. With decreasing altitude *Podocarpus*, *Bischofia*, *Euodia*, Myrtaceae, *Plerandra* and *Dicksonia* comp. become more common.

5. The Wainisavulevu ridge samples (W1 to W7) are all similar. The dominant pollen types are *Freycinetia*, *Celtis* comp., *Bischofia*, Melastomataceae, Poaceae, Cyperaceae, Cyatheaceae, *Dicksonia* comp., and *Polypodium*.

3.1.3 Discussion

The major difference between the forests of Taveuni and central Viti Levu is the greater role played by the gymnosperms on Viti Levu. This is attributed to generally lower and more seasonal rainfall on the main island, although it might be expected that leeward Taveuni would experience a similar rainfall regime. Differentiation between high and low altitude forests is more marked. At high elevations common taxa include Cunoniaceae, *Ficus*, *Syzygium* and Arecaceae, all shrouded with epiphytic *Freycinetia*, ferns and orchids. On Viti Levu, apart from very exposed ridges, *Podocarpus*, *Dacrydium* and *Agathis* are also common. At lower elevations *Endospermum*, *Dysoxylum*, *Myristica*, *Planchonella*, *Palaquium* and Cyatheaceae are far more common.

Some of these vegetation differences are apparent in the surface pollen samples. *Dacrydium* and *Bischofia* are most common in the Viti Levu samples, whereas Arecaceae, *Freycinetia* and Urticaceae 1 are better represented in the Taveuni samples. Cunoniaceae is obviously common only in surface samples from the very highest altitude forests, while *Endospermum* and *Omalanthus* show their greatest representation in the samples from lower elevations.

There are certain similarities between the samples from leeward Taveuni, especially samples T9 to T15, and those from the Viti Levu plateau. These areas experience similar climatic conditions and support comparable forests, with the exception of the presence of *Dacrydium* and *Agathis* in the Viti Levu forests. Myrtaceae pollen is more common in these surface samples than in any of the others.

The samples from the Tagimaucia basin are markedly different from the other surface samples, and this may be largely attributed to the fact that these are the only samples collected any distance from the forest in an open environment with surrounding swamp. The forest taxa represented in the Tagimaucia basin samples must be transported to the sample sites by wind, except in the case of the lake bottom sample which has a water-borne pollen component as well. This may suggest that those taxa well represented in these samples, including Urticaceae 1, *Ascarina*, *Acalypha* and *Bischofia*, are largely wind dispersed. Other taxa which have sustained high representation in these samples, for example, Arecaceae, *Freycinetia*, *Lepironia* comp., Cyatheaceae, and *Lycopodium* are components of the swamp vegetation as well as being represented in the surrounding forests (see Chapter 4), and have only short distances to travel to the surface sample sites. Some taxa which are common in the surrounding forests, for example, *Macaranga*, *Acalypha*, *Calophyllum*, *Podocarpus* and *Rapanea*, are represented in the pollen spectra from the swamp surface samples. Walker and Flenley (1979) suggest that several of these pollen taxa have equivalent or over-representation in modern Papua New Guinea pollen spectra. Similar principles seem apply to the pollen representation of the Fijian taxa. Many of the more common forest trees in the Tagimaucia area, for example, *Planchonella*, *Ficus*, *Neubergia*, *Sterculia* and *Geniostoma* are not well-represented in the swamp surface samples. Some of these taxa occasionally achieve high pollen representation in the forest surface samples, which suggests that these taxa have poor pollen dispersal outside the forest.

The Wainisavulevu samples, because of their location along a newly cut track on a ridge (for the development of the Monasavu Hydro-electricity Scheme) probably have a high pollen input from wind-borne sources. It is therefore possible that the relatively high values for *Celtis* comp. and *Bischofia* are representative of dispersal from distant sources. *Bischofia* pollen is also present in the Tagimaucia basin surface samples, although not in the surrounding vegetation, which is suggestive of regional dispersal. Berry and Howard (1973) suggest this taxon is common in forest edge situations or on steep scree slopes in the Wainisavulevu region. The distribution of *Bischofia* argues that its pollen might be more readily available for wind transport than many other Fijian forest taxa. The very high values for Cyperaceae and Poaceae is the result of the presence of these taxa in the vegetation which has established along the track.

Table 3.2 summarises the representation and dispersal characteristics of the common pollen and spore types.

The Fijian surface pollen data tend to agree with the general conclusions on tropical pollen rain which were outlined above. While the mixing of several samples and then processing a subsample tended to reduce the domination of the pollen count by a single local taxon, it emphasized the diversity of the pollen spectra from the forests and the lack of differentiation between pollen assemblages from the different areas. There are few indicator taxa which may be used to identify certain vegetation types, for example, the presence of Cunoniaceae pollen apparently characterises the high altitude ridge forests of both Taveuni and Viti Levu; lower altitude forests with high rainfall are characterised by *Endosperm* pollen; forests from middle elevations with more or less seasonal rainfall have moderately high representation of Myrtaceae pollen; and the forests of Viti Levu with gymnosperm emergents are characterised by *Dacrydium* pollen.

Little upward transport of pollen is apparent in the Fijian samples, probably not because of any lack of upslope winds, but more likely because the dense vegetation reduces the release of pollen above the canopy for wind dispersal in any direction.

The Tagimaucia basin data indicate that the fossil samples from the swamp and lake sites might be expected to contain pollen mainly from extra-local sources, with additional input from a few taxa which apparently have regional dispersal capabilities.

3.2 Coastal Pollen Rain

The sites selected for fossil pollen analysis in coastal Fiji are located within the delta systems of two of the major rivers of Viti Levu. The origin of these sites is likely to be related to past movements of sea level, and their vegetation development related to processes within coastal environments. To assess the

Table 3.2: Representation and Dispersal of Common Pollen and Spore Taxa

Acalypha:	Equivalent representation from extra-local sources.
Arecaceae:	Equivalent representation from local and extra-local sources.
Ascarina:	Possibly over-represented from regional sources.
Bischofia:	Over-representation from regional sources.
Celtis comp:	Over-represented outside the forest from regional sources.
Commersonia:	Over-representation from local sources.
Coprosma:	Equivalent representation from local sources.
Cunoniaceae:	Equivalent to over-representation from local sources.
Dacrydium:	Under-representation from local sources.
Freycinetia:	Over-representation from local and extra-local sources.
Macaranga:	Equivalent to over-representation from extra-local and regional sources.
Myrtaceae:	Equivalent representation from local sources.
Podocarpus:	Equivalent to over-representation from local and extra-local sources.
Urticaceae:	Equivalent to over-representation from local, extra-local and regional sources.
Calophyllum, Dysoxylum, Elaeocarpus, Homalium, Ilex, Maesa, Melastomataceae & *Plerandra*:	Equivalent to under-representation from mainly local sources.
Endospermum, Euodia, Omalanthus, Rapanea, Poaceae, Cyperaceae, and most pteridophytes:	Equivalent to over-representation from local and extra-local sources.

development of both the wetland and dryland vegetation communities in the coastal regions it is necessary to establish the pollen analogues for the various coastal vegetation communities and to establish whether the environment of deposition affects the dryland pollen spectra in any way.

3.2.1 Methods

Surface mud samples were collected along a transect which passed across the Navua Delta (see Figure 3.2 for location of the delta) from *Metroxylon vitiense* (sago) swamp at the base of the hills; through *Pandanus pyriformis* with *Sphagnum cuspidatum*, sedges and grasses; to *Pandanus* with the mangrove fern, *Acrostichum aureum*; to *Acrostichum* with the mangrove taxa *Lumnitzera littorea* and *Brugiera gymnorhiza*; *Brugiera* with *Acrostichum*; and finally to pure *Rhizophora stylosa/R.samoensis* stands at the river edge of the mangroves. Three samples were also collected from mangroves in north-western Viti Levu, near Lautoka (see Figure 3.2) where conditions are drier and the mangrove vegetation much less dense. Samples were collected from the seaward margin of the mangroves (mostly *Rhizophora stylosa* and *R. samoensis*), from the mid-tide zone of mangroves (*Rhizophora* with scattered *Brugiera gymnorhiza*, and from the rarely inundated inland margin of the mangroves which has a sparse cover of mangrove seedlings only. The site characteristics of the surface sample sites are presented on Table 3.3.

Small surface mud samples were collected from within approximately a 1 m^2 area of each of the vegetation types selected. These small samples from within each site were then amalgamated, bagged and labelled. In the laboratory the samples were well mixed and then a 1 cm^3 subsample was extracted and processed using the standard method described above. Two samples were collected from sites where *Sphagnum* hummocks were apparent (N2 and N3), one from the hummock and one from the swamp surface below the hummock. This was to determine whether a significant water-borne component is reaching the swamp surface, while the *Sphagnum* hummocks may be receiving only air-borne pollen.

Subsurface samples from 10 cm depth were also collected from all of the samples on the Lautoka mangrove transect to examine whether any degradation of the pollen was occurring during sedimentation in these drier areas. This was largely carried out because it was noted during preliminary examination of the basal sediments from the coastal pollen cores, which appeared to be of mangrove origin, that mangrove pollen (indeed pollen of any type) was sparse or absent. It has been observed that at the aerobic sediment-water interface in mangroves, degradation

Table 3.3: Site Characteristics of Coastal Surface Samples

Sample No.	Site Characteristics
N1	Sago swamp, dominated by *Metroxylon vitiense* with occasional climbing ferns including *Stenochlaena palustris, Diplazium* sp., *Lygodium reticulatum & Nephrolepis biserrata.*
N2	Sago swamp merging with *Pandanus pyriformis* as the substrate changes from colluvium to peat.
N3	*Pandanus pyriformis* swamp with an understorey of sedges including *Rhynchospora corymbosa, Pycreus polystachyos, Cyperus pilosus, Kyllinga polyphylla, Eleocharis ochrostachys & Scleria polycarpa.* Pteridophytes are also common, including *Nephrolepis biserrata, Sphaerostephanos unitus & Dicranopteris linearis.* Remnants of *Sphagnum cuspidatum* suggest it formed the ground cover before burning and drainage.
N4	*Pandanus pyriformis* with *Acrostichum aureum* and the above ferns, sedges and remnant *Sphagnum cuspidatum.*
N5	*Pandanus pyriformis* with the above ferns, sedges and the grasses, *Paspalum orbiculare, Bracciara mutica & Sacciolepis indica.*
N6	Scattered *Pandanus pyriformis* with abundant *Acrostichum aureum, Dicranopteris linearis, Sphaerostephanos unitus & Nephrolepis biserrata.*
N7	Vegetation as in N6, but this area had been recently burned.
M1	Landward margin of the mangroves with vegetation composed of *Lumnitzera littorea, Brugiera gymnorrhiza, Pandanus pyriformis & Acrostichum aureum.*
M2	Vegetation dominated by *Brugiera gymnorrhiza, Pandanus pyriformis & Acrostichum aureum.*
M3	Mangrove vegetation on the edge of the Lobau River dominated by *Rhizophora stylosa.*
L1	*Rhizophora stylosa & R. samoensis* at the seaward margin of the mangroves.
L2	*Rhizophora stylosa & R. samoensis* with scattered *Brugiera gymnorrhiza.*
L3	Landward margin of mangrove zone with surface devoid of vegetation, except scattered *Rhizophora* seedlings.

rates of organic material are extremely high, although decomposition slows markedly once the material is buried (Albright 1976; Boto 1982). Since mangroves also occupy open sedimentary systems, sediments (with pollen) may be removed by tidal action or locally redistributed by the same action or by bioturbation (Grindrod in press). It is possible that these factors may be responsible for the lack of pollen in the basal fossil samples.

Pollen counts proceeded on these samples until at least 200 grains, excluding *Metroxylon vitiense*, *Pandanus* and pteridophytes which were often over-represented, had been recorded.

3.2.2 Results

The results of the coastal surface pollen counts are presented on Figure 3.4. The counts are shown as percentages of a pollen sum which consists of all dryland taxa, while pteridophytes, *Metroxylon*, *Pandanus* and Cyperaceae, which had often erratic representation and therefore were likely to distort the percentage representation of other taxa, are excluded. The most common taxa are shown individually on the pollen diagram.

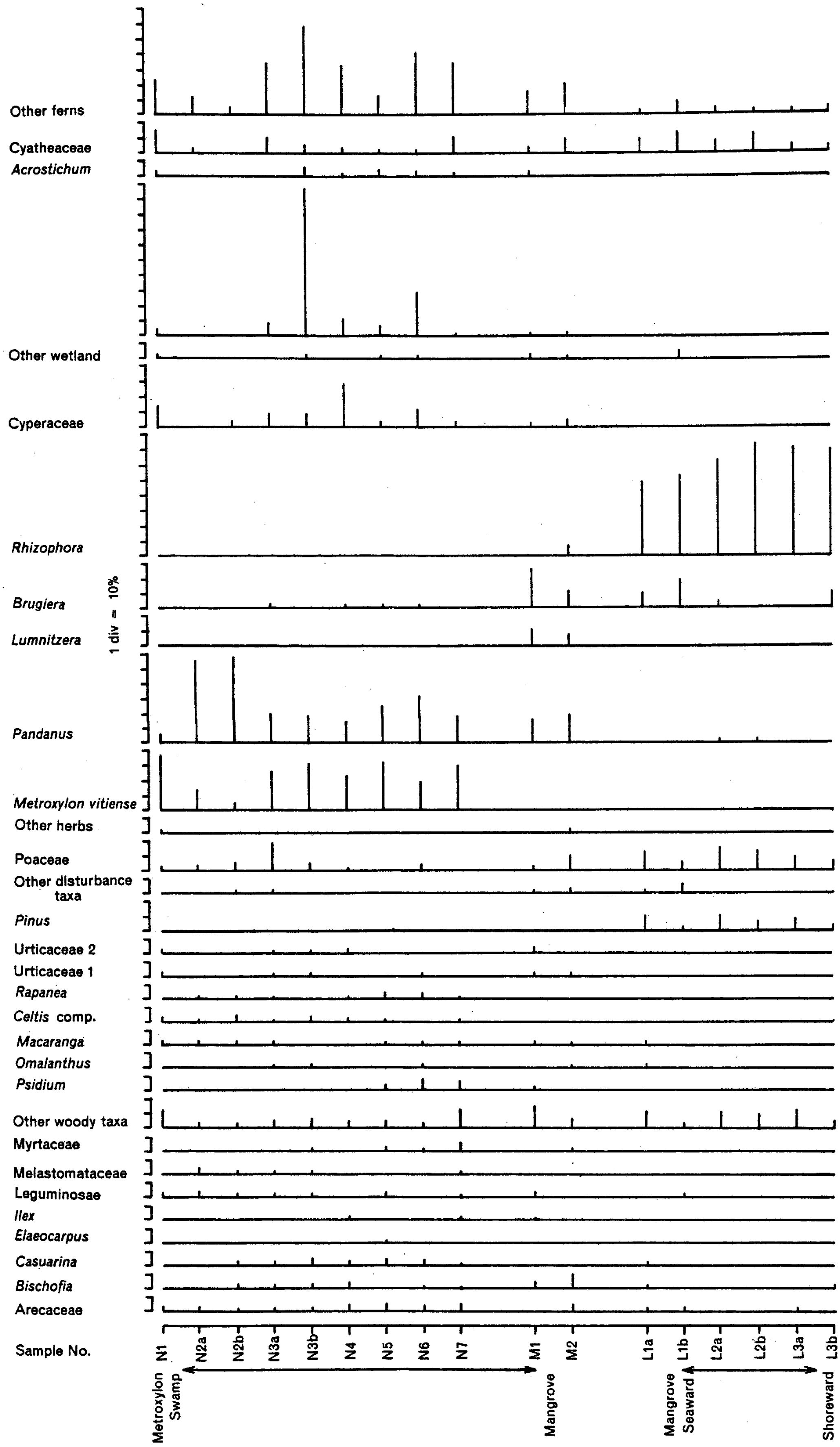
Pinus is well-represented in the Lautoka mangrove samples, because of the extensive *Pinus caribbea* plantations in north-western Viti Levu. *Casuarina* is well-represented in the Navua surface samples, but not in the Lautoka samples. This is probably because of the absence of any dryland forest fringing the coast near Lautoka at present, whereas small patches of forest with *Casuarina* persist near Navua. There are otherwise few patterns in the representation of dryland taxa in these coastal surface samples, but as might be expected there is a very distinctive pattern of variation in the wetland taxa.

The Navua surface pollen spectra (N1 to N7) are dominated by the swamp taxa *Metroxylon* and *Pandanus*, but there is no consistent pattern of change along the transect. Cyperaceae and *Acrostichum* comp. are more common towards the seaward end of the transect, which is a reflection of their increased representation in the wetland vegetation. However, Poaceae, which also becomes more important in the vegetation, does not show any increase in representation.

The mangrove surface samples from the Navua Delta (M1 and M2) are characterised by the mangrove taxa *Lumnitzera* and *Brugiera*. *Pandanus* also has moderate representation, but *Rhizophora* is poorly represented. Unfortunately, sample M3, which was from a stand of pure *Rhizophora*, contained very little pollen and that which was present was badly eroded.

The Lautoka samples are all dominated by *Rhizophora* pollen with some *Brugiera*.

Figure 3-4: Coastal Surface Pollen Spectra



3.2.3 Discussion

The patterns which are evident in the surface pollen samples from the coastal sites in Fiji allow the following conclusions to be made, which may be later utilised in interpretation of the fossil pollen spectra.

1. There is little variation in the representation of dryland taxa across the range of the Navua Delta sites suggesting that variations in dryland taxa in the fossil samples should not simply represent changes in the local swamp environment.

2. There is little consistent variation between the hummock and hollow samples, suggesting that the microtopography in the wetlands does not affect pollen representation.

3. *Metroxylon* pollen is apparently restricted to freshwater swamp surface samples within 750 m or so of the source vegetation, and does not disperse, either by water or air, to mangrove sites downstream. This is despite the obviously high pollen production of *Metroxylon*.

4. *Rhizophora* and *Brugiera* pollen is probably not dispersed inland, in any significant amount, from the mangrove fringe.

5. There is no consistent variation between the surface and subsurface samples on the Lautoka transect, and pollen contained within the samples was equally badly eroded, suggesting that bioturbation and tidal action effectively mix the sediments and pollen, and that burial is not rapid enough to preclude this activity diminishing the pollen catch.

CHAPTER 4

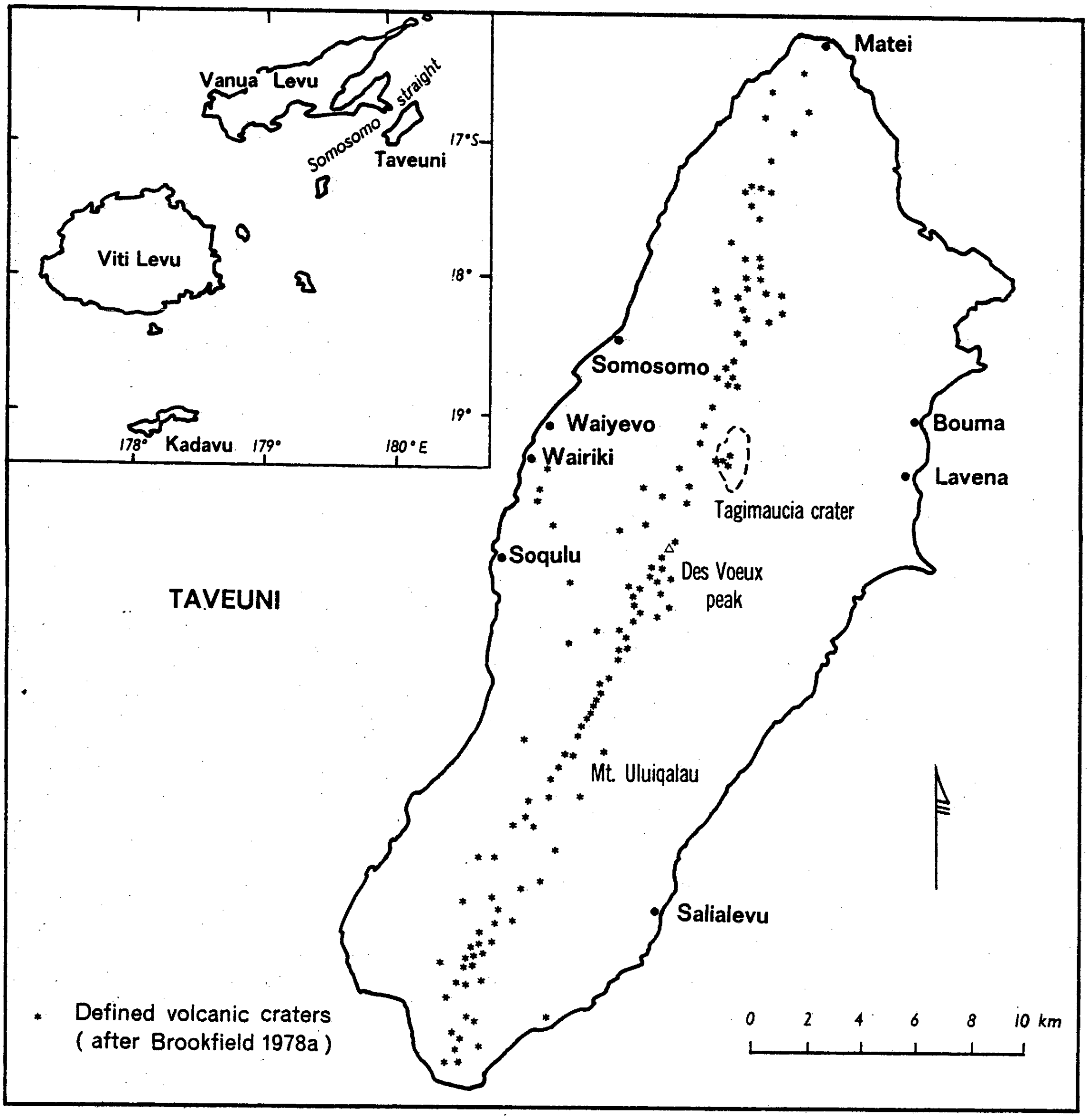
THE POLLEN SITES: LAKE TAGIMAUCIA

After a period of reconnaissance in Fiji, Lake Tagimaucia on Taveuni (Figure 4.1) was chosen as the site most likely to yield a long record of vegetation history of the islands. While the age of the basin is uncertain, it is suggested that the north-eastern part of Taveuni which contains the Lake Tagimaucia basin is probably Pliocene in age (Brookfield 1978a; Rodda and Kroenke 1985). Potentially ancient sites of organic deposition are rare on the oceanic islands of the south-west Pacific, and Lake Tagimaucia represents a unique opportunity for investigating the past vegetation of the Pacific islands.

The site is at a similar altitude (ca. 800 m) and latitude (ca. 17°S) as palynological sites on the Atherton Tableland in north-eastern Australia (Kershaw 1976) and it is intended to compare their respective vegetation histories in a later chapter. It is possible that the Tagimaucia record will help to determine how much the vegetation changes on the Atherton Tableland reflect local variation due to sea level fluctuations.

Lake Tagimaucia is situated on Taveuni, the third largest island of the Fiji Group. The island lies 180 km to the north-east of Viti Levu, but is separated from Vanua Levu only by the narrow Somosomo Strait (Figure 4.1). Taveuni is about 40 km long and 10 km wide and the long axis is oriented approximately north-east to south-west. A narrow coastal plain to the north, south and west of the island rises steeply to the main ridge of mountains which has an average altitude of 860 m and culminates at Mt. Uluiqalau (1243 m). The ridge consists of a series of volcanic cones, including the caldera which contains Lake Tagimaucia and its surrounding swamp.

Figure 4-1: Location of Taveuni



4.1 The Regional Setting: Taveuni

4.1.1 Geology and Soils

The basement rocks of Taveuni are basaltic and eruption occurred during the most recent period of volcanic activity in Fiji: the Pliocene to Recent Ba volcanic phase, coinciding with the opening of the Lau-Harve basin. While the majority of the volcanic rocks on Taveuni are thought to be Pleistocene to Recent in age, those of the north-east corner of the island are probably Pliocene, up to three million years old (Rodda and Kroenke 1985). Young volcanic cones are clearly visible on aerial photographs and these have been marked on Figure 4.1: they roughly form the central ridge. It has been suggested that the cones are outlets of a single fissure or magma source (Ibbotson 1960; Frost 1974). Charcoal, associated with a human occupation horizon, sandwiched between layers of volcanic ash, scoria and cinders is dated at 2050 BP (Frost 1974), which indicates that volcanism has occurred within at least the last 2000 years and within the period of human occupation.

The soils of Taveuni are derived from this Pliocene to Recent volcanic material and are highly fertile, although fertility declines with altitude. Evolution of the soils has been rapid under the weathering effects of an extremely humid climate.

The soil types are distributed according to altitude, degree of slope and amount of rainfall. Most of the soils in the very wet areas (>4000 mm rainfall per annum) are friable with high percolation rates and waterlogging is rare. These soils tend to become unstable after removal of forest cover (either by natural means or human intervention), especially on very steep slopes. Many of the soils are characterised by the presence of vesicular basalt boulders and gravel, increasing in abundance with depth in the soil, although they are often exposed where surface erosion has occurred. A high organic component is common in many topsoils, especially those under dense forest cover (Twyford and Wright 1965).

The greatest contrast in the soils of Taveuni, however, is between the youthful andosols of the south and the mature ferrasols of the north (Denis 1978). This distinction is linked to the age of the parent volcanic material.

4.1.2 Climate

Taveuni's north-east to south-west orientation and central ridge of mountains combine to intercept the prevailing rain-bearing south-east trade winds. Orographic uplift results in extremely cloudy conditions on the ridge accompanied by high rainfall. At Des Voeux Peak (1220 m) the average rainfall is 9768 mm per annum (Public Works Department, Hydrology Section, Taveuni, records 1976 to 1983). The windward coast also receives high rainfall, with an annual average of 5784 mm at Salialevu (Fiji Meteorological Service 1981). These areas fall within climatic zone F of Jenkins and Lesslie's (1973) classification. The rainshadow effect on the leeward coast is evident and annual averages range from 2432 mm at Waiyevo to 3082 mm at Soqulu (Fiji Meteorological Service 1981), and these areas fall in climatic zone E. The rainshadow effect from Taveuni extends across Somosomo Strait to the east coast of Vanua Levu. Monthly and annual averages for all stations mentioned are presented in Table 4.1 and their locations are shown on Figure 4.1.

Table 4-1: Rainfall Averages for Taveuni

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
D.V. Pk.	729	663	585	934	825	533	774	827	760	1115	1158	872	9768
Salialevu	496	444	438	566	522	451	386	412	459	504	605	501	5784
Waiyevo	290	300	291	264	196	128	79	105	117	184	223	255	2432
Soqulu	415	385	368	356	218	171	106	93	174	174	328	294	3082

(data, in mm, from Fiji Meteorological Service 1981 and Public Works Department, Hydrology Section, Taveuni, Records)

Seasonal variation in rainfall is minimal at Salialevu and Des Voeux Peak, although there are a considerable range of values evident in individual monthly totals. Presumably this situation applies to the rest of windward Taveuni. Both the Waiyevo and Soqulu records show a dry season from June to October with high variability.

Rainfall gradients are therefore dramatic on Taveuni. Des Voeux Peak and Waiyevo are about 7 km apart: the rainfall difference amounts to 7000 mm per annum - approximately 1 mm per metre travelled!

Temperature data are available from Matei Airfield, yielding an average annual temperature of 25.8°C with a small seasonal range from 24.2°C in August to 27.2°C in March (Fiji Meteorological Service 1982). Using the lapse rate of 6.4°C per 1000 m, which was determined for Viti Levu (see Chapter 2.2.3), average temperatures on Des Voeux Peak are likely to be about 18°C.

4.1.3 Vegetation

The vegetation of Taveuni is known from the collections of Seemann (1862), Smith (1979, 1981, 1985) and Brownlie (1977), however, most of these collections were from limited areas or had a specific taxonomic purpose and no general description of the vegetation exists.

It is likely that variation in vegetation on the island is related to altitude and the steep rainfall gradients, since soil fertility is uniformly high (Denis 1983). In an attempt to characterise the vegetation of Taveuni, several forest transects were described on Des Voeux Peak, at intervals from the summit ridge, at about 1200 m, to 460 m on the west coast, at approximately 200 m intervals, and on the slopes behind Bouma Village on the east coast. Transects were also described from near Lake Tagimaucia; one from the forest boundary with the swamp, one across a small volcanic cone raised above the main part of the swamp, and one from the ridge above the basin. Each transect consisted of 100 trees which overhung the transect line, which was the walking track except at Lake Tagimaucia where the swamp edge formed the first transect line and the second was a cleared line running directly over the volcanic cone. Taxa were identified in the field or collected and later identified at least to generic level at the SUVA herbarium. The occurrence and abundance of taxa is presented on Table 4.2.

There are several taxa which are obviously common throughout most of the sampled forests on Taveuni. These include *Macaranga harveyana*, *Calophyllum vitiense*, *Syzygium effusum*, and *Cyathea alta.* There are also taxa which occur infrequently but do not appear to be restricted to any particular area on the island (e.g. *Aglaia* sp. and *Elattostachys falcata*). Other taxa are more restricted in their distribution, although this may simply reflect the low number of transects attempted.

The forest surrounding the Lake Tagimaucia basin and possibly much of the eastern side of Taveuni's main ridge has abundant *Calophyllum vitiense*, *Dysoxylum* sp. 1, and *Podocarpus neriifolius*, and commonly has *Cryptocarya hornei*, *Veitchia simulans*, and *Astronidium degeneri*. *Cyathea medullaris*, *Rapanea myricifolia*, *Ficus storckii*, *F. vitiensis*, *Neubergia alata*, *Metrosideros collina*, *Sterculia vitiensis*, *Maesa tabacifolia*, and *Geniostoma vitiense* are all common or abundant in at least one of the Tagimaucia transects.

The high altitude forests under extremely high rainfall on Des Voeux Peak commonly have *Scaevola floribunda*, *Clinostigma exorrhiza*, *Ficus vitiensis*, *Astronidium* sp., *Dysoxylum gillespieanum*, and especially species of Cunoniaceae, including *Acsmithii vitiensis*, *Geissois imthurnii* and *G. ternata.* The most striking features of these forests, however, are their stunted appearance and the

Table 4.2: Taxa Recorded on Vegetation transects, Taveuni
4.2A: Taxa Occurring in More Than One Transect

Transects: 1 = Edge of Tagimaucia basin, 800 m asl
2 = On small crater within Tagimaucia basin, 800 m asl
3 = Ridge at edge of Tagimaucia catchment, 860 m asl
4 = Des Voeux Peak 1220 m asl
5 = Des Voeux Peak 975 m asl
6 = Des Voeux Peak 760 m asl
7 = Des Voeux Peak 460 m asl
8 = Bouma 60 m

+ = present ++ = common +++ = abundant

	Transect							
Taxa	1	2	3	4	5	6	7	8
Macaranga harveyana	+++	+	+	++	+++	++	+	++
Cyathea alta	++	+++		++	++	+		+
Calophyllum vitiense	+++	+++	+++		+++	+++	+	+
Syzygium effusum			+	++	++	+	++	+++
Dysoxylum sp. 1	++	+	+++	++				+++
Podocarpus neriifolius	++	+	++					+
Aglaia sp.			++		+	+	+	+
Elattostachys falcata	+					++	+	
Sterculia dasphylla	+				+			+
Syzygium gracilipes	++	+						
Gynochthodes ovalifolia	+	+						
Timonius affinis	+	+						
Turrillia ferruginea	+	+						
Planchonella sp. 3	++	++						
Cryptocarya hornei	+	+	++					
Veitchia simulans	+	+	+					
Astronidium degeneri	+	+	+					
Calycosia petiolata	+	+	+					
Scaevola floribunda	+			++				
Rapanea myricifolia	++		+	+	+			
Clinostigma exorrhiza	++			+	+++			
Ficus sp.1		+		+				
Faradaya ovalifolia		+		+				
Cyathea medullaris		+++						
Ficus storckii		++		+	+			
Ficus vitiensis		++		+++	+			
Neubergia alata		++	++					
Randia vitiensis		+	+					
Ficus pritchardii		+		+	+			
Flacourtia sp.		+			+			
Citronella vitiensis			++	+				
Elaeocarpus sp.			+		+			
Decaspermum vitiense			+		+	+		
Astronidium sp.				+++	+			
Geissois imthurnii				+	+			
Palaquium hornei				+	+	+		

Table 4.2A cont'd

Taxa	Transect 1	2	3	4	5	6	7	8
Omalanthus nutans					+	+		
Planchonella sp.1					++	+	+++	
Dysoxylum gillespieanum					+++	+++	+++	
Dysoxulum richii					+	+++	++	
Hedycarya dorstenioides					+		+	
Alstonia vitiensis						+	+	
Arytera concolor						+	+	
Randia sp.				++				+
Cryptocarya sp.				++	+			+
Trichospermum richii					+	+		+
Endospermum macrophyllum						++	+	++
Heritiera ornithocephala						+	+	+
Palaquium sp 2						++		+
Cyathea lunulata							+	+
Myristica grandifolia							+++	++

Table 4.2B: Taxa Occurring in Only One Transect

Syzygium sp.2	+		
Palaquium fidjiense	+		
Pandanus taveuniensis	+		
Pittosporum pickeringii	+		
Pittosporum rhytidocarpum	+		
Arytera brackenridgei	+		
Cupaniopsis amoena	+		
Ilex vitiensis	+		
Metrosideros collina	++		
Sterculia vitiensis	++		
Heliconia paka		++	
Physokentia rosea		+	
Linociera vitiensis		+	
Marattia smithii		+	
Clidemia hirta		+	
Sukunia pentagonioides		+	
Spiraeanthemum katakata		+	
Acalypha sp.		+	
Smilax vitiensis		+	
Psychotria sp.		+	
Elatostema insulare		+	
Plerandra insolita		+	
Spiraeanthemum serratum		+	
Acalypha sp.		+	
Maesa tabacifolia		++	
Geniostoma vitiense		+++	
Cyathocalyx sp.			+
Xylopia sp.			+
Endiandra sp.			+
Astronidium confertifolium			+
Litsea sp.			+

Table 4.2B cont'd

Taxa	Transect 1	 2	 3	 4	 5	 6	 7	 8
Fagraea vitiensis				+				
Cyrtandra tempestii				+				
Ficus barclayana				+				
Pipturus platyphyllus				+				
Freycinetia graeffei				+				
Geissois ternata				+				
Dysoxylum lenticillare				+				
Ardisia sp.				+				
Timonius affinis				++				
Maesa insularis				++				
Acsmithia vitiensis				+++				
Garcinia myrtifolia					+			
Parasponia andersonii					+			
Neuhergia corynocarpa					++			
Capparis quinifolia						+		
Bischofia javanica						+		
Cupaniopsis leptobotrys						+		
Cynometra sp.						+		
Hernandia sp.						+		
Parinari insularum						+		
Alphitonia zyzyphoides						++		
Calophyllum neo-ebudicum						++		
Planchonella sp. 2							+	
Myristica castaneifolia							+	
Pagiantha thurstonii							+	
Ficus benjaminia							++	
Spiraeanthemum brackenridgei								+
Cleistocalyx sp.								+
Psychotria sp.								+
Dysoxylum sp. 2								+
Phaleria glabra								+
Ervatamia orientalis								+
Alstonia sp.								+
Arytera sp.								+
Barringtonia edulis								+
Agathis vitiensis								++
Hernandia olivacea								++
Medusanthera vitiensis								++

presence of abundant Zingiberaceae and Strelitzeaceae and epiphytic *Freycinetia graeffei*, ferns and mosses.

With decreasing elevation and rainfall the forests are dominated by species of the Meliaceae (*Dysoxylum gillespianum*, *D. richii*, and *Aglaia* sp.), *Endospermum macrophyllum*, *Myristica castaneifolia*, *M. grandifolia*, species of Sapotaceae (*Palaquium* sp.1, sp.2, and *Planchonella* sp.1) and Clusiaceae (*Garcinia myrtifolia*, *Calophyllum neo-ebudicum*, and *C. vitiense*). Certain taxa are apparently restricted to the wetter ridge areas and eastern side of Taveuni, for example, *Podocarpus neriifolius*, *Dysoxylum* sp.1 and *Rapanea myricifolia*.

Several taxa were recorded only from the Bouma site (see Table 4.2b) including *Agathis vitiensis* which elsewhere in Fiji is common mainly at higher elevations.

Unlike most of the other Fijian islands, Taveuni has no *talasiga* grass or fernlands. Notably several of the typical *talasiga* species (e.g. *Dicranopteris linearis*, *Pteridium esculentum* and *Miscanthus floridulus*) are found chiefly on acidic soils (Latham 1983), which are rare on Taveuni. The absence of a dry zone on the island is also unfavourable for the growth and spread of *talasiga* species. If, as Latham (1979, 1983) suggests, the *talasiga* is a relict of drier periods in the past, it may well be that conditions on Taveuni were never dry enough to support *talasiga*.

4.1.4 Human Impact

A number of archaeological sites have been discovered and excavated on Taveuni (Frost 1974), see Figure 4.2. These are fortified sites, although in some cases excavation revealed earlier, unfortified settlements below the surface fortifications. The earliest date for occupation of 2050+/-150 BP derives from an unfortified site, Navolivoli (site VaL 16/10), beneath 3 m of volcanic ash and soil within a volcanic cone. A stratigraphically distinct ditch-fortified habitation area occurs at the surface of Navolivoli and ^{14}C dating of a hearth from a house-mound yielded an age 710+/-80 BP (Frost 1974). The youngest archaeological occupation site is Navuga (site VaL 15/33) which Frost suggests was occupied after extensive european contact on Taveuni in the mid-nineteenth century.

Archaeological sites on Taveuni form three clusters (Figure 4.2), the largest of of which (11 sites) is located on the south-western tip of the island. The second cluster is near the present site of Bouma Village and three sites cluster south of Somosomo, including a site on Korolevu Island. The sites are generally within 2 km of the coast and below 200 m asl. There is one exception, Navuga at 800 m

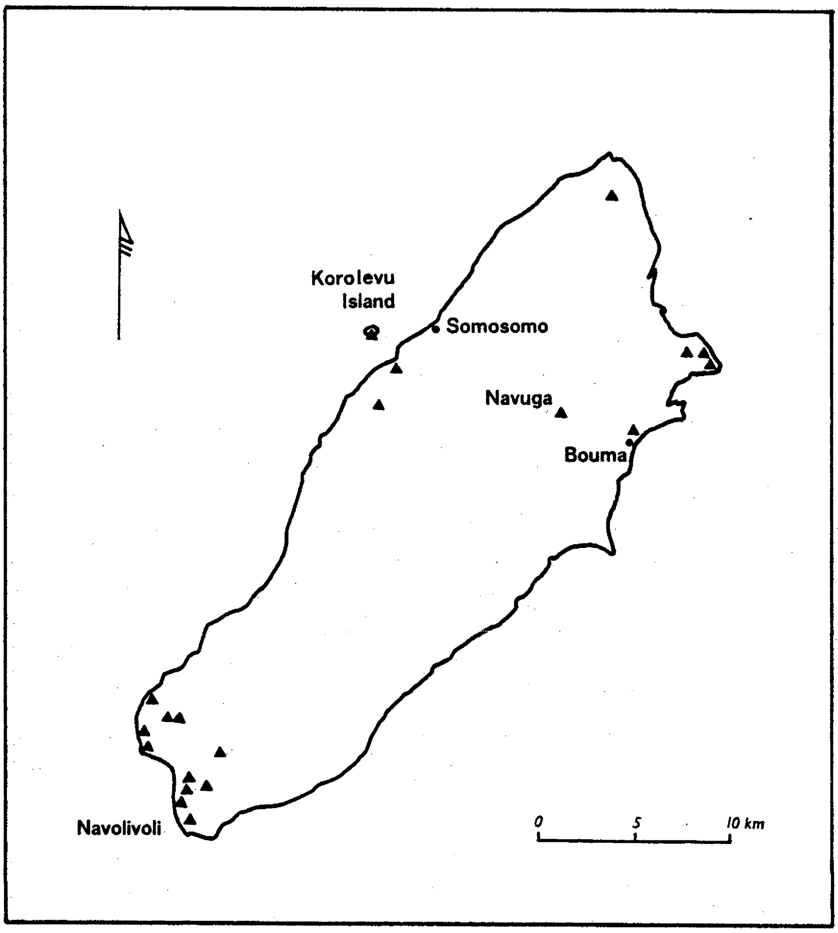


Figure 4-2: Archaeological Sites on Taveuni

asl and 3.5 km from the coast. Notably this site post-dates european contact and was occupied only after the original village site was sold as freehold land (Frost 1974).

The inland and steep areas of Taveuni apparently contain no archaeological sites. The dense vegetation and rugged terrain may have prevented their discovery, but there seems to be no local knowledge of former village sites in inland areas and certainly no permanent habitation there at present. It is likely that disturbance of the environment by man in prehistoric times would have been restricted to the coastal areas, especially the south-west.

The post-european period in Taveuni has been characterised by the alienation of much native land for plantations, initially cotton, followed by attempts at growing coffee and sugar, and finally and more successfully, coconuts for oil (Brookfield 1978b). While many of the original large plantations of the late nineteenth and early twentieth centuries have been broken into smaller units, cultivation in Taveuni remains restricted to the plantation sites on the flat and gently sloping land along the south-western and north-western parts of the island. Subsistence gardens extend slightly higher up the slopes, but the high rainfall and steep gradients of the interior and east coast of Taveuni have halted further expansion of such activities.

Roads extend along the coast from Lavena Village, around the north and west to Salialevu in the south-east, but the rugged east coast, punctuated by several waterfalls, has remained untouched. A single road built to service telecommunications transmitters extends to the central ridge top at Des Voeux Peak from Wairiki. Several rarely used and ill-defined tracks exist in the central part of Taveuni.

4.2 Lake Tagimaucia: Local Environment

4.2.1 The Physical Setting

Swamp and open water covers an area of 213 ha within the Lake Tagimaucia basin, a volcanic caldera situated on the eastern side of Taveuni's main ridge at about 820 m above sea level. The eastern side of the basin is formed by a fault scarp 60 to 80 m above the present floor of the crater, which continues to the south-west of Lake Tagimaucia for about 2 km. Several small volcanic cones rise up from the general level of the crater and form islands within the swamp (Figures 4.1, 4.3). The walls of the caldera and surrounding mountains are formed of Pliocene to Pleistocene basic volcanics, while these smaller craters appear to be exclusively Pleistocene to Recent in age.

The catchment covers about 619 ha, and extends up the eastern slopes of Taveuni's ridge (to 1100 m) to the west, includes the short, steep slopes of the scarp face in the east and the wall of the caldera in the north. A single outflow channel, Wainisairi Creek, has formed a steep, rocky channel, about 4 m wide and 50 cm deep, through the scarp wall at the south-east end of the crater. The creek drops to the east coast of Taveuni in a series of waterfalls. A small pond has formed in the swamp behind the outlet with steep walls of sedge peat. The peat is present up to the edge of the scarp wall in this part of the crater.

Much of the floor of the crater is covered by sedge peat swamp which is currently infilling the basin and encroaching upon the open water areas. At the base of the catchment slopes there is often an accumulation of colluvium which grades onto the peat surface. In some places, however, the edge of the peat is

Figure 4-3: The Lake Tagimaucia Basin from Des Voeux Peak

marked by a 2 to 3 m deep, narrow water-filled fissure and coring of the central part of the swamp reveals there is in fact a floating peat mat some 2 to 3 m thick. The peat mat is itself broken by fissures, the whole forming large peat islands which enclose several lakes, the largest of which is Lake Tagimaucia.

Rainfall tends to run off the peat into the fissures and the lake and it is likely that much of the surface flow from the catchment reaches Wainisairi Creek after flowing along the fissures and beneath the peat islands. The narrow outflow is unable to cope with the backup in the lake after sustained heavy rain, and the lake level and the level of the floating peat may rise by at least 1 m at these times.

Climatic conditions in the basin are dominated by the effect of orographic uplift of the prevailing moist south-east trade winds, which produces very high rainfall and sustained cloudiness. No rainfall figures are available for the site but about 9800 mm per annum is received at Des Voeux Peak, 6 km to the south-west of Tagimaucia and it is likely that a similar figure could be expected at the lake due to its position on the windward slopes just below the central ridge. Short-term observations show cloudiness is high and relative humidity varies between 94 and 98% for most of the year (Southern *et al.* in press 1986). The cloud is not very deep and is often fleeting in the area. Overall radiation may be high despite the cloudiness. Annual temperatures at Tagimaucia may average 20.5°C, assuming a lapse rate of 6.4°C per 1000 m and an average temperature at sea level of 25.8°C.

The results of chemical analyses of water samples from the lake collected at intervals over a two year period (Southern *et al.* in press 1986) suggest the lake chemistry lies close to the averages for rainwater with minor input from basaltic groundwater. This is a reflection of the very high rainfall in the area, the small size of the catchment and the short period of contact between the water and the substrate.

There is a very limited fauna within the Tagimaucia basin. Non-aquatic invertebrates are restricted to a few lepidopterans and adults of aquatic insect larvae. Aquatic invertebrates are similarly low in both abundance and diversity. Observed vertebrates included a single eel (probably *Anguilla marmorate* Quoy and Gaimard), a single specimen of the Pacific islands python, *Candoia bibroni* Hombron and Jacquinot, juveniles of the introduced cane toad, *Bufo marinus* L., although other frog calls were heard and the villagers from Somosomo claimed the Fijian ground frog, *Platymantis vitianus* Dumeril., had been seen at Tagimaucia. Bird life on the swamp proper was apparently restricted to swamp harriers, *Circus approximans approximans* Peale, but many other birds occupied the surrounding forests.

4.2.2 Vegetation

Catchment vegetation

The catchment vegetation above the level of swamp and open water was characterised by three of the transects discussed above (Table 4.2). It consists of thick stunted rainforest (8 to 18 m high), with abundant ferns and mosses and often emergent treeferns (mainly *Cyathea alta* and *C. medullaris*) and palms (mainly *Veitchia simulans* and *Clinostigma exorrhiza*). Common tree taxa include *Calophyllum vitiense*, *Macaranga harveyana*, *Geniostoma vitiense*, *Dysoxylum* sp., *Rapanea myricifolia*, *Palaquium hornei*, *Podocarpus neriifolius*, and *Neubergia alata*. The understorey is dominated by climbing *Freycinetia graeffei*, *F. storckii*, *Gynochthodes ovalifolia*, *Medinilla heterophylla*, *Hoya diptera*, *Macropiper puberulum*, *Peperomia* sp., *Selaginella* sp., *Leptopteris wilkesiana* and species of Urticaceae. This vegetation may be classified as tropical evergreen ombrophilous cloud forest (see Chapter 2.4.1), however, the gymnosperms generally characteristic of this forest type are uncommon here.

A combination of very steep slopes, abundant rainfall, and occasional tectonic activity in the catchment results in a high degree of slope instability. The ground exposed after mass movement of surface material is quickly colonised by the ferns *Dicranopteris caudata* and more commonly *Lycopodium cernuum*. This ground cover is gradually replaced by stands of the palms *Veitchia simulans* and *Clinostigma exorrhiza* and the treeferns *Cyathea alta* and *C. medullaris*. Other forest taxa colonise from the forest edge, but the palms and treeferns remain emergent for a considerable period. Figure 4.4 shows an obvious patch of disturbed vegetation within the forest which local guides indicated was the site of a landslip during a minor earth tremor some 10 years previously.

Swamp vegetation

The vegetation on the swamp surface comprises three community types which are roughly correlated with substrate and nutrient supply. There is a Pandanaceae dominated open shrubland in areas where colluvium and alluvium has accumulated around the swamp margin near the slope bases, open sedgelands which occur on peat in the centre of the swamp, and sparse algal communities within the open water bodies. These communities usually have abrupt boundaries and may be mapped from aerial photographs, see Figure 4.5. Southern *et al.* (in press 1986) sampled a transect passing through these three communities and the species content and abundance was recorded in each of the vegetation types. Abundance was recorded as either present, common or abundant. This information is summarised in Table 4.3 and the vegetation types are described below.

Figure 4-4: Catchment Vegetation with Emergent Palms and Treeferns

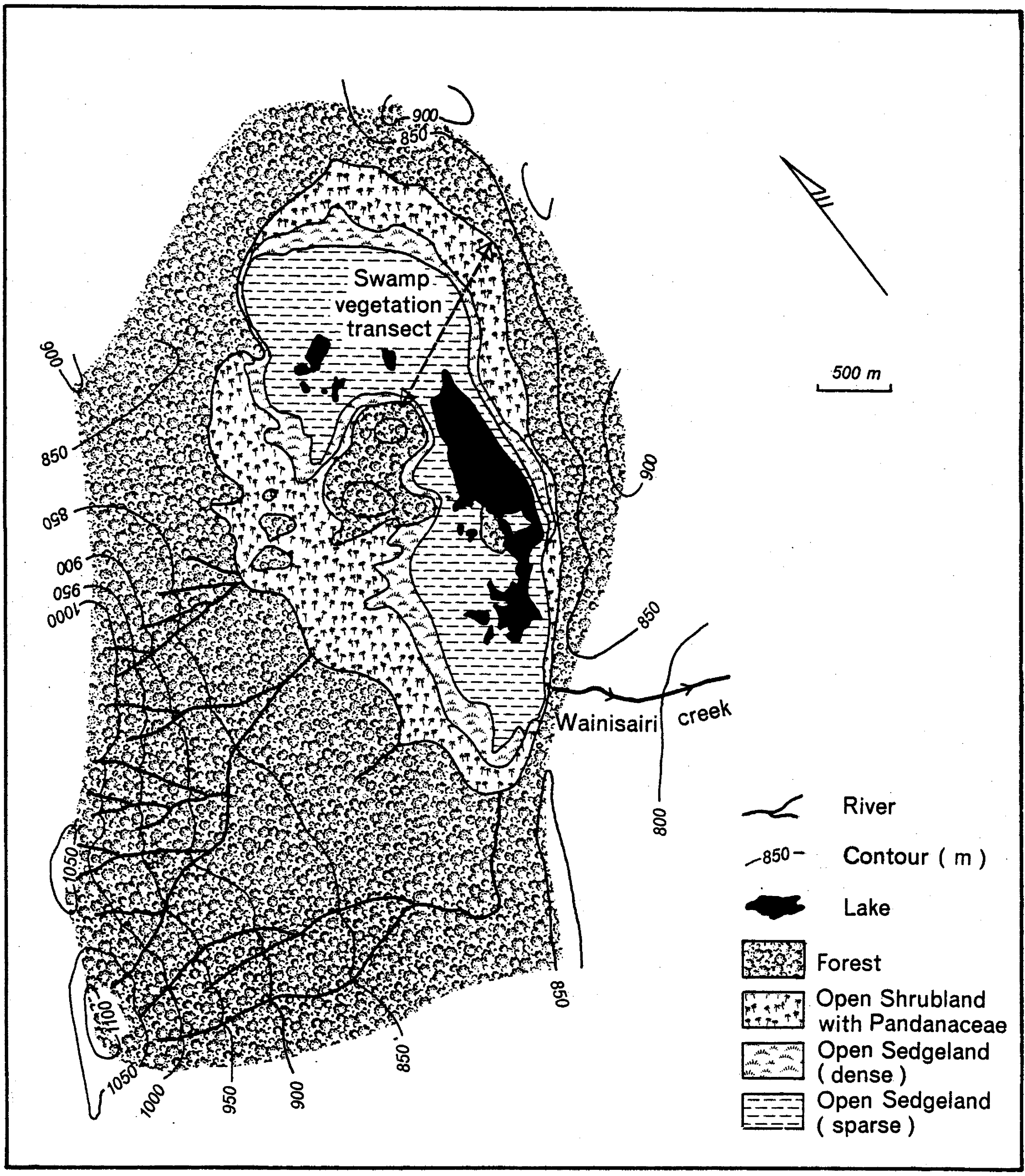


Figure 4-5: Vegetation Distributions in the Lake Tagimaucia Basin

Table 4.3: Tagimaucia Swamp Vegetation (after Southern *et al.* in press 1986)

Species	Pandanaceae Community 1	Pandanaceae Community 2	Cyperaceae Community 1	Cyperaceae Community 2	Cyperaceae Community 3	Cyperaceae Community 4
Trees & shrubs						
Acsmithia vitiensis	+	+				
**Clidemia hirta*			+			
Garcinia myrtifolia	+	+				
Geniostoma vitiense		+				
Melastoma denticulatum		+				
Metrosideros collina	+	+				
Pittosporum pickeringii		+				
Rapanea myricifolia	+	+				
Scaevola floribunda						+
Syzygium gracilipes	+	+				
Weinmannia affinis	+	+				+
Pandanaceae & Arecaceae						
Freycinetia pritchardii						+
Freycinetia storckii	+++	+				
Pandanus taveuniensis		++				
Physokentia rosea						+
Cyperaceae						
Eleocharis dulcis		+++	+++			
Eleocharis ochrostachys			++	+++		
Hypolytrum nemorum	+					
Lepidosperma sp.					+	
Lepironia articulata		+++	++	++	+++	+
Machaerina falcata		+	+			
**Rhynchospora corymbosa*		++	++			
Herbs						
**Centella asiatica*		+	+			
**Mikania micrantha*		+	++			
**Paspalum distichum*		+	+			
**Paspalum orbiculare*		+	+			
**Polygonum dichotomum*			++			
Spathoglottis pacifica					+	+
Ferns & fern allies						
Culcita straminea						+
Dicranopteris caudata		++			+	+
Lycopodium cernuum					+	+
Nephrolepis hirsutula		+				
Bryophytes						
Leucopogon sanctum					++	
Sphagnum cuspidatum						++

Site numbers refer to community descriptions given in the text.

* = European introductions.

Open Shrubland with Pandanaceae

This community occurs on waterlogged areas with an inorganic substrate, i.e. the colluvium-alluvium at the swamp margins. It may be divided into two major types.

1. Near streams where alluvium is abundant the vegetation is characterised by scattered stunted specimens of *Pandanus taveuniensis* which are covered with a dense growth of *Freycinetia storckii*.
2. Where the substrate has a higher organic content, particularly where there is a mix of colluvium and peat, the vegetation is dominated by *Pandanus taveuniensis* 3 to 5 m tall, with a ground cover of sedges; largely *Eleocharis dulcis* and *Lepironia articulata*.

Open Sedgelands

The vegetation dominated by Cyperaceae may be divided into four zones along a transect from the largely inorganic marginal sediments to the highly organic peats at the centre of the swamp.

1. At the base of the slopes, where surface run-off contributes to both nutrients and moisture levels, the vegetation comprises *Eleocharis dulcis* and *E. ochrostachys* with a few dicotyledonous herbs, including the introduced species *Polygonum dichotomum* and *Mikania micrantha*. This zone is narrow, perhaps 5 to 10 m wide and is often flooded to a depth of 0.2 to 1 m, depending upon preceding rainfall conditions.
2. As the substrate becomes more peaty the dicotyledonous herbs become less common and this zone consists almost entirely of *E. ochrostachys*. This zone is also usually flooded to a depth of 1 m or so and varies in width from a few metres near very steep slopes to 100 m wide when next to *Pandanus* communities.
3. This zone is often separated from the preceding zone by one of the deep narrow fissures mentioned above. The substrate is peat and the vegetation is dominated by *Lepironia articulata* growing to 2 m tall along the fissures with a high biomass (2 to 4 kg m^{-2}), but reducing in both height and density (biomass 0.05 to 1 kg m^{-2}) towards the centre of the peat islands. The ground between the sparse *Lepironia* clumps is covered by the moss *Leucobryum sanctum* or a jelly-like mass of algae dominated by Cyanophyta, including *Anabaena*, *Oscillatoria*, *Spirulina* and various Chroococcaceae; Chlorophyta, including *Zygnema*, *Spirogyra*, *Ulothrix*, *Chlamydomonas*; and various Desmidiaceae, including *Tetmemorus*, *Cosmarium*, *Closterium*, and *Pleurotaenium*; and Bacillariophyta including *Frustulia* and *Eunotia*. Small shallow pools occur on the peat surface and these have very sparse communities of *Lepironia* and another sedge, provisionally indentified as a species of *Lepidosperma*.
4. At the lakeward margins of the peat islands the surface is often slightly raised above the general water level. In these areas and other places which are for some reason slightly raised (e.g. old Pandanaceae stumps) there are patches of more diverse vegetation. Notably *Sphagnum*

> *cuspidatum* forms raised hummocks and these are colonised by several, woody shrubs, small trees and unidentified mosses. Common taxa include *Metrosideros collina*, *Scaevola floribunda*, *Weinmannia affinis*, the palm *Physokentia rosea*, and several ferns including *Culcita straminea*, *Dicranopteris caudata*, and *Lycopodium cernuum*.

Open water

The open water bodies in the basin support a sparse phytoplankton community dominated by Bacillariophyta, including *Frustulia*, *Pinnularia*, *Eunotia*, and *Surirella*; Desmidiaceae, including *Closterium*, *Pleurotaenium*, *Euastrum*, *Staurastrum*, and *Tetmemorus*; Zygnemataceae, including *Zygnema* and *Spirogyra*; and Cyanophyta including *Oscillatoria*. *Nitella* was also present, but uncommon.

The Tagimaucia swamp and lake are unique in Fiji; the basin probably represents the only undisturbed wetland ecosystem in the island group and certainly supports vegetation communities not found in other wetlands. The site may be unique in the south-west Pacific. This is largely because the islands rarely experience geological conditions conducive to the formation of closed basins which accumulate sediments for long periods of time. Most swamp sites described are either ephemeral, close to sea level and therefore related to past movements of the sea, or severely disturbed.

The swamp flora is extremely small at Tagimaucia and while this is undoubtedly partly the result of very low primary productivity and nutrient inputs to the lake and swamp, it is also a reflection of the very small number of obligate native wetland species in Fiji (Ash and Ash 1984). The swamps of Viti Levu have much more diverse floras, but these are largely comprised of introduced species and it is possible that the sites owe their origin at least partly to the activities of man. Lake Tagimaucia, which shows a minimum amount of disturbance, is dominated by species which must have arrived via long distance dispersal from either within Fiji or further afield. The native wetland species present in Fiji are widely distributed beyond the south-west Pacific (Koyama 1979; Smith 1979). Migratory waterfowl may have been the dispersing agent since the wetlands provide suitable habitats on migratory routes. There has apparently been no *in situ* development of a swamp flora presumably because, on an evolutionary time-scale, wetland habitats in Fiji are restricted in area and ephemeral.

While there are no similar wetland ecosystems in the south-west Pacific, a comparison with Tasek Bera in Malaysia (Furtado and Mori 1982) is of interest. This lowland site has similar water chemistry, algal productivity and a swamp flora also dominated by *Lepironia articulata* and *Pandanus* (*Pandanus helicopus*). Differences between the sites lie in the greater diversity of flora and fauna at Tasek

Bera, largely because of biogeographic factors (i.e. the greater isolation of Fiji). The vegetation history of Tasek Bera (Morley 1981, 1982b) reveals a complex, but short (4400 years), record of swamp vegetation development from dominantly riparian vegetation to *Pandanus* dominated swamp with some swamp forest nearby, and finally to the *Lepironia/Pandanus* mix present at the site today. Morley suggests that the reduction of *Pandanus* and increase in *Lepironia* over the past 600 years is due to anthropogenic burning on the swamp surface to maintain navigation channels. There is no suggestion that swamp forest has been recently present in the Lake Tagimaucia basin, and the open *Lepironia articulata* dominated swamp communities are not maintained by fire. It would seem that nutrient influx to Lake Tagimaucia is too low to maintain other vegetation types, in contrast to the situation at Tasek Bera.

4.3 Swamp Stratigraphy

A stratigraphic cross-section of Tagimaucia crater was undertaken using a hand-held D-section corer. The cores were extracted along an approximately longitudinal transect of the site from locations indicated on Figure 4.6 and described in the field. The stratigraphic information is presented on Figure 4.7. Except towards the margins of the crater, the base of the sediments was not reached with the available extension rods for the corer.

There is an apparent difference in the stratigraphic profiles from the northern and southern parts of the crater. To the north of the lake (cores 1 to 5), a typical profile from the surface down is as follows:

1. A surface root mat of sedge roots bound together with a jelly-like mass of algae, similar in appearance to the surface algal mat described above.
2. A layer of highly organic sedge peat with abundant well preserved remains of sedge roots and shoots. This blends gradually into the underlying horizon, or is occasionally separated from it by a layer of water 50 to 100 cm in depth.
3. The next horizon consists of homogeneous lake sediments which are mealy red/brown in appearance with abundant fragmented plant inclusions.
4. This layer is interrupted at depth (ca. 8 to 9 m) by a narrow band of volcanic ash, gritty in texture and contained in a blackened organic matrix. The lake sediments continue beneath the ash horizon.
5. Where basal sediments were reached they consisted of a stiff mixture of clay and sand. Occasionally the lake sediments were banded within this inorganic mixture.

From the main lake south the profiles (cores 6 to 12) are slightly different.

Figure 4-6: Location of Stratigraphic Core Sites

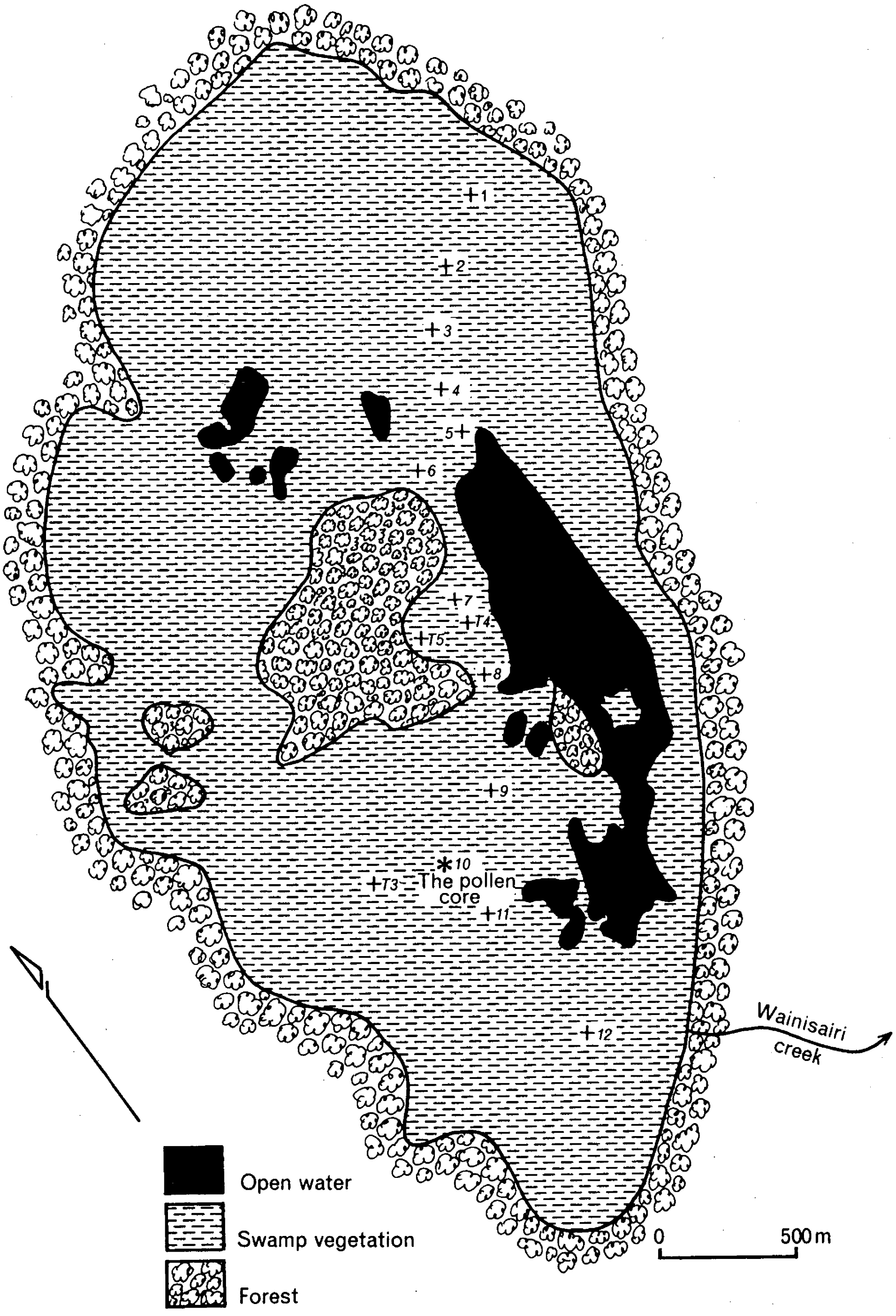
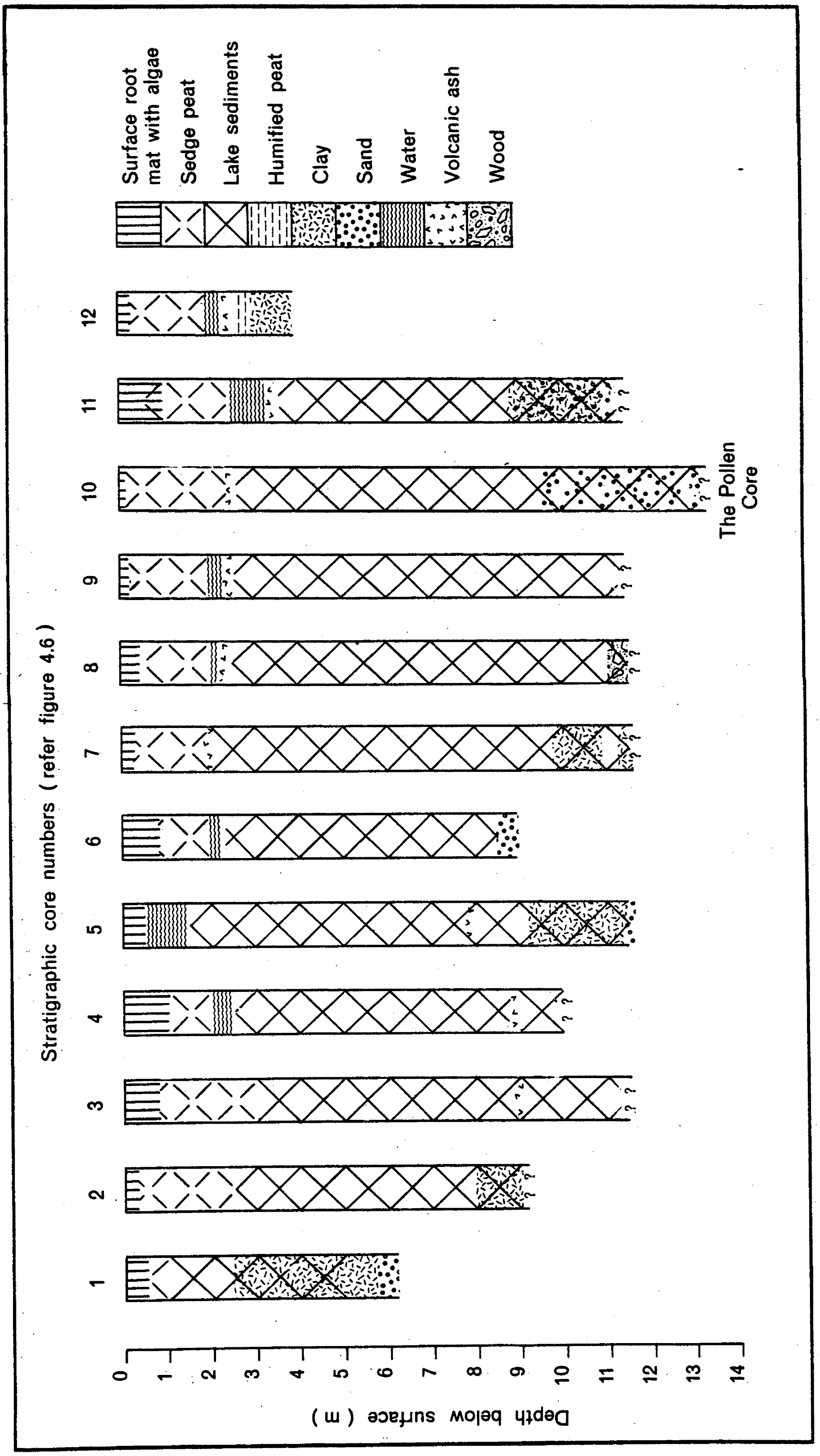


Figure 4-7: Stratigraphy of the Tagimaucia Crater



The division between the sedge peat and the lake sediments is marked by a layer of volcanic ash, often with a layer of water above the ash, such that the peat is effectively floating. This stratigraphic break occurs consistently around 2 to 3 m in depth and there is no evidence for a volcanic ash horizon deeper in the cores corresponding with the ash layer at 8 to 9 m depth in the north. In all other respects the sedimentary units themselves are the same as those encountered in the northern part of the crater.

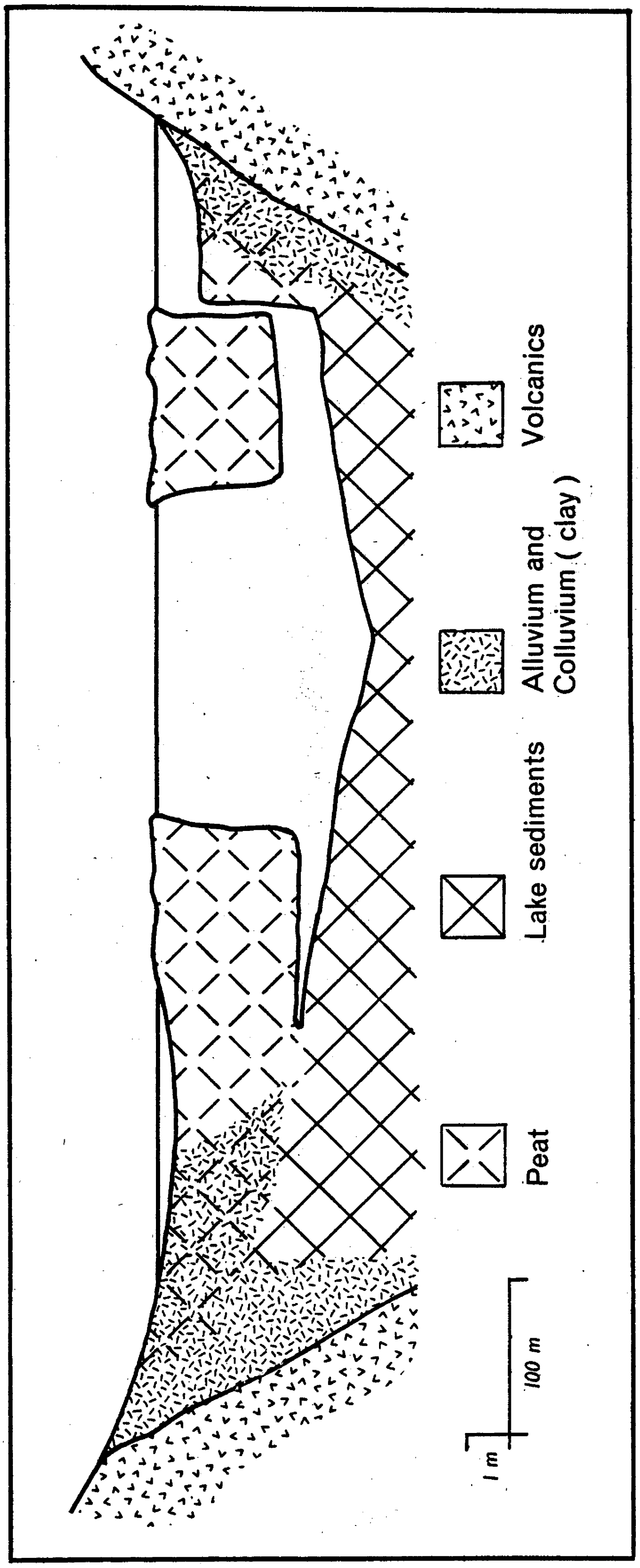
The depth of the water layer beneath the peat horizon was observed to vary on different occasions at the swamp, depending upon preceding rainfall conditions. Periods of extremely heavy rainfall resulted in the build up of waters in the basin. The lake level was observed to have risen by about one metre in November 1984 after three months of heavy continuous rainfall. This extra water apparently continued as a layer under much of the peat, raising the peat surface around the basin margin by up to one metre also. It is likely that the water layer separates the peat from the underlying lake sediments largely because the peat is composed of much less dense and compact material. A suggested cross-section of the Tagimaucia basin under flood conditions is presented in Figure 4.8.

The complicated stratigraphy of the site indicates the development of the Lake Tagimaucia basin can only be tentatively described and analysed. It would appear from the presence of homogeneous lake sediments at depth in most of the stratigraphic profiles that the basin once contained a much more extensive body of open water than at present. The presence of inorganic clays and gravels at the base of cores 5 and 6 suggests a tongue of colluvium may extend eastwards across the floor of the basin from the large volcanic island and may have divided the basin in the past. This may partly explain the apparent differences in stratigraphic development between the northern and southern parts of the basin. The very steep slopes to the north and east may indicate the basin is deeper at the base of these slopes.

Deposition of organic material is interrupted by a layer of volcanic ash, the top of which is dated at 1500+/-120 BP in core 10, the pollen core, giving a minimum age for the eruption. A date of 2050+/-150 BP (Frost 1974) beneath a layer of ash to the south of Tagimaucia may therefore record the same period of volcanic activity.

The much deeper occurrence of a volcanic ash horizon in the northern stratigraphic cores is difficult to explain. Accumulation rates in the tropics are often high (c.f. Tasek Bera in Malaysia, with 3.9 m accumulating in about 660 years, Morley 1982b; and 9.3 m in 990 years accumulated in Rano Kao crater on

Figure 4-8: Suggested Cross-Section of the Tagimaucia Basin in Flood



Easter Island, Flenley 1979b) and up to 9 m of material may well have accumulated in 1500 years. This seems unlikely, given the very low primary productivity of the lake at present, although a massive input of nutrients from a fall of ash may have been sufficient to boost productivity and cause rapid accumulation in the lake basin.

In cores 7 to 12 the ash layer separates lake from swamp sediments, with or without a layer of water above the ash. It is tempting to suggest the fall of ash somehow precipitated the stratigraphic change. At the time of deposition of the ash the lake waters in this part of the basin are unlikely to have been more than 2 to 3 m deep, based upon the level of the outflow channel. After the fall of ash a sedge swamp was apparently established over much of the southern part of the basin. Certainly an influx of nutrients derived from the volcanic material would have dramatically increased the productivity of any surrounding swamp communities. Notably, the present day biomass of swamp communities with access to nutrients near the lake edge and along fissures is 40 times greater than that on central parts of the peat swamp where oligotrophic conditions prevail (Southern *et al.* in press 1986). A consequence of the difference in production between the middle and margins of the peat surface is that expansion across the lake surface is likely to occur far more rapidly than vertical peat growth. It is possible then that a rapid horizontal spread of swamp vegetation might have occurred after an input of nutrients, encroaching rapidly on the open waters of the lake. It will be further discussed in relation to the swamp vegetation history.

It is possible that the steeply sloping edges of the basin to the north may have precluded the same sequence of events occurring there. Swamp communities may have expanded from the margins, but the base of the lake may have been deeper and lateral expansion may have been restricted.

Upward growth of the peat appears to have slowed considerably in the very recent past. The oligotrophic conditions over much of the swamp surface have reduced productivity and it is likely that these conditions have prevailed since the swamp surface reached the approximate level of the outflow channel. Lateral growth of the swamp is probably continuing and it seems likely that the entire basin will be infilled by swamp sediments in the relatively near future.

4.4 The Pollen Diagrams

4.4.1 Methods

The pollen core (No. 10 in Figure 4.7) was extracted using a hand-held D-section corer with extension rods to a depth of 12.5 m. The sedimentary material was extracted in 50 cm lengths from alternate, adjacent holes so that contamination of the upper 10 cm or so of sediment by the driving end of the D-section did not occur. The material was placed in PVC tubing cut to 50 cm lengths, labelled, wrapped and sealed in plastic for transport to the laboratory for analysis. The basal 75 cm of core was collected using a piston sampler and was retained in the same manner. The base of the sediments was not reached with the available equipment in July 1983 and a second attempt to acquire deeper sediments in November 1984 using waterpipe extensions to the D-section failed due to the inadequacy of the improvised equipment while extracting sediments from 12.5 to 13 m.

Samples for pollen analysis were collected from the core at 20 cm intervals in the laboratory. A 1 cm slice from each sampling level was removed and a 1 cm^3 sample (measured by displacement in distilled water) was taken from the centre of each for pollen analysis. This sampling procedure avoided the likelihood of contamination from the outside of the core. The remainder of the slice was used for determination of percentage moisture and percentage organic content, the latter estimated from percentage loss on ignition. Samples for moisture content were weighed, dried at 100°C for 24 hours, then re-weighed and the moisture was estimated as the ratio of wet to dry weight. The dried sample was then placed in a pre-weighed crucible, ignited in a muffle furnace at 600°C for 2 hours, re-weighed and the percentage loss on ignition calculated.

The 1 cm^3 samples for pollen analysis were prepared following the standard technique described above in Chapter 3 for surface samples. During preparation of the fossil samples, volumes of added silicone oil and the aliquot on each slide were measured to facilitate quantitative manipulation of the data at a later stage.

Pollen counts proceeded on evenly spaced transects until at least 200 grains of dryland taxa had been recorded where possible. Pollen concentrations were too low to allow a meaningful count in the surface sample and samples from 100 to 180 cm in the core. The number of transects taken to reach the total was also recorded. All other taxa encountered during these counts were also recorded, such that the total pollen and spore count ranged from 228 to 1193 (pollen and spore counts are tabulated in Appendix B). The dryland pollen count formed the sum for the pollen diagram. Certain taxa were excluded from the sum for the following reasons. *Freycinetia*, which generally grows as a climber in the forest canopy, *Pandanus*, which occurs sparingly in the forest, and Cyperaceae, which may grow on the forest floor, also grow abundantly on the swamp in the Tagimaucia basin. They have fluctuating values in the fossil pollen counts and the highest values probably indicate over-representation due to a local source. Information from surface samples suggests *Freycinetia* pollen may be over-represented wherever it occurs. Low values for Cyperaceae pollen were recorded in undisturbed forest surface samples, but are unlikely to be transported out of a forest situation except by water. *Pandanus* was similarly rarely recorded from forest surface samples. These taxa have been excluded from the pollen sum to avoid distortion of the percentages of other dryland taxa.

Pteridophytes, which may have their spores transported by water, often show over-representation in pollen counts. For this reason pteridophyte values have been calculated outside the pollen sum.

An attempt was made to determine the concentrations of carbonised particles in the sediments using both the point-count method of Clark (1982) and the counting method outlined in Singh *et al.* (1981). The concentrations were too low to allow a reliable estimation of carbonised particle content and it is assumed that this result reflects the lack of fires in the Tagimaucia catchment during the period of sedimentation. Given the extremely wet conditions prevailing and the probable lack of human disturbance in the area, this result is not surprising.

4.4.2 ^{14}C Dating and Stratigraphy of the Pollen Core

^{14}C dates

Material for ^{14}C assay was initially collected from the major stratigraphic break in the core at 255 to 275 cm and at the base of the collected core, 1310 to 1325 cm. After the pollen counts had been partially completed, further material was submitted from levels coinciding with major changes in the pollen spectra, that is, at 802 to 818 cm, 940 to 955 cm, 1060 to 1068 cm and 1200 to 1220 cm. The following dates were reported for this core:

Code no.	Depth in core (cm)	Reported date (years BP)
ANU-3811	255 - 275	1500+/-120
ANU-4560	802 - 818	6310+/-90
ANU-4561	940 - 955	9030+/-90
ANU-4577	1060 - 1068	11700+/-120
ANU-4578	1200 - 1220	10760+/-130
ANU-3812	1310 - 1325	14120+/-370

There is an apparent reversal towards the base of the core, with ANU-4578 appearing too young. ANU-4577 and 4578 were submitted at the same time and it is possible that the samples were accidentally substituted for one another at that time, however, the age/depth curve presented on Figure 4.9

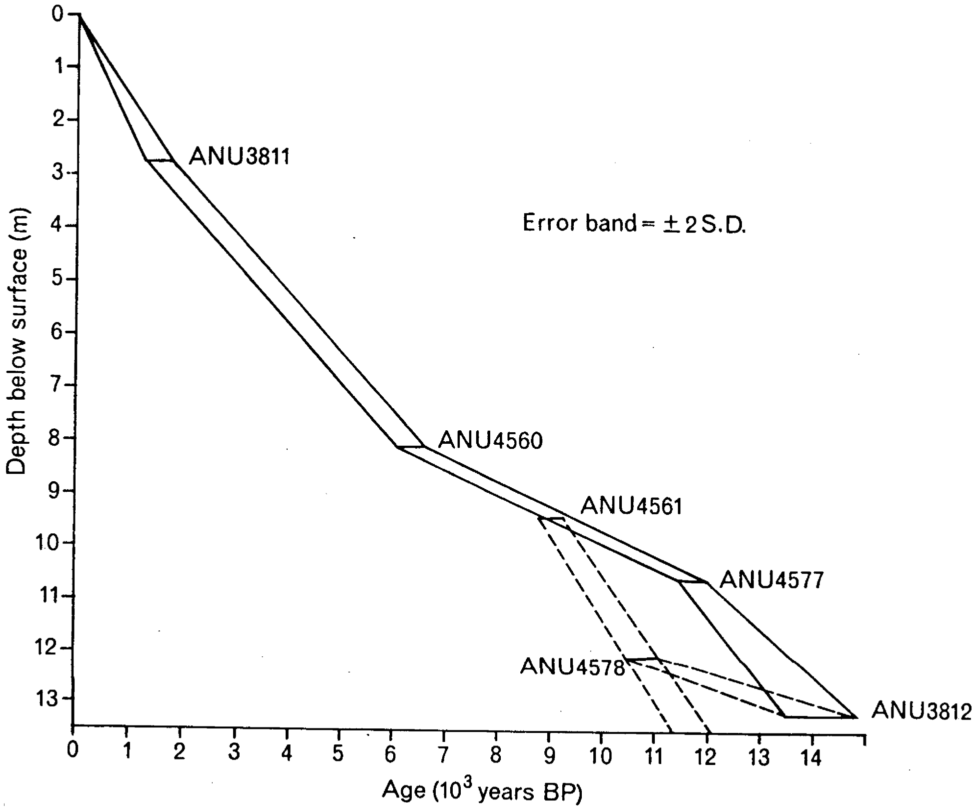


Figure 4-9: Age/Depth Curve for the Tagimaucia Pollen Core

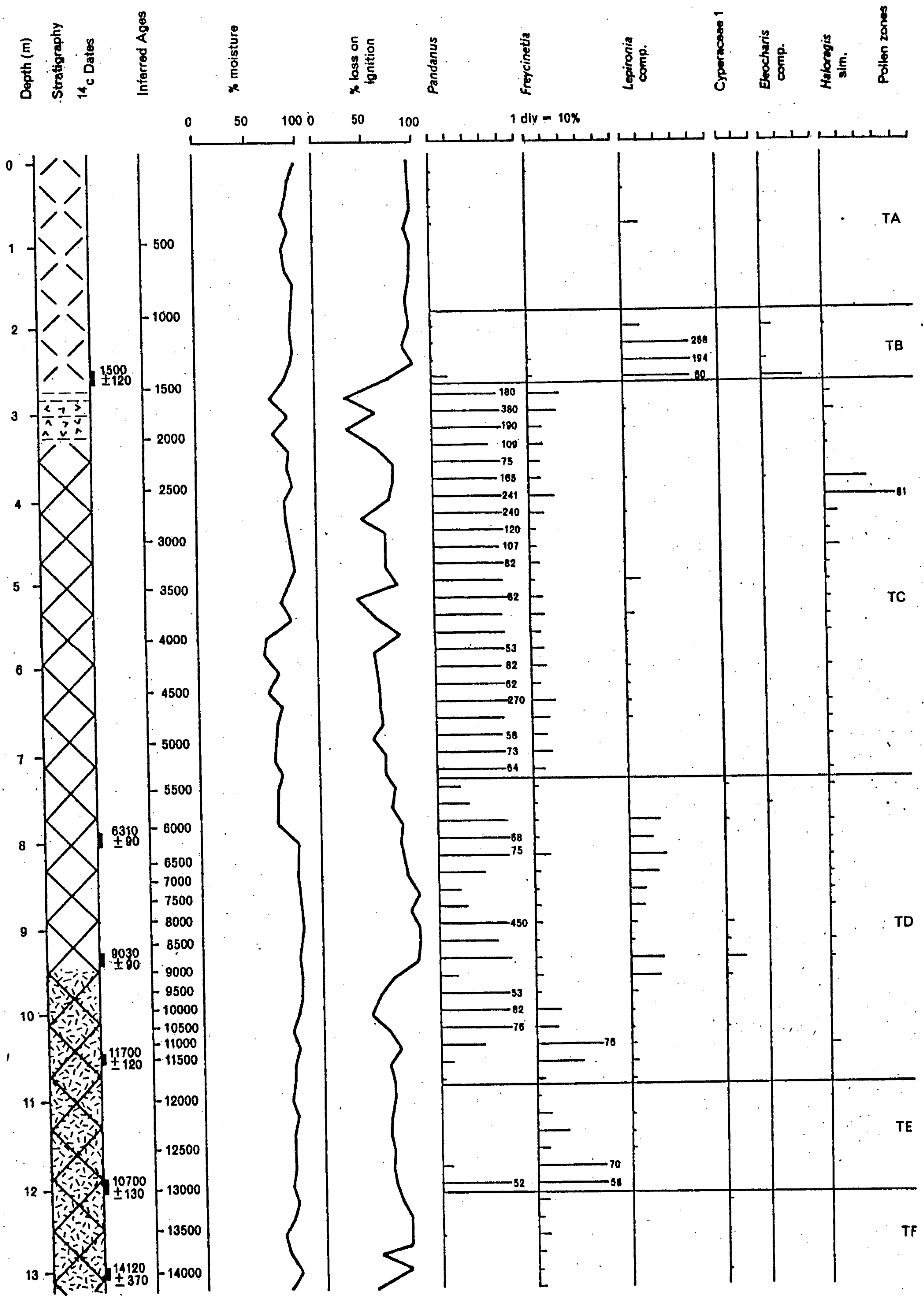
shows that the date of 11 700 BP lies along a straight line between the basal date and the two upper dates of 9030 and 6310 BP. This suggests a fairly steady depostion rate which the homogeneous sediments indicate at these depths. Reversing ANU-4577 and 4578 results in a marked disruption of the age/depth curve, while there is no apparent change in sedimentation. The most likely explanation for the apparent reversal of this sample is the incorporation of younger carbon in ANU-4578 either during or after the extraction of the core. Younger material may have adhered to the outside of the D-section corer whilst being lowered into the ground and while care was taken to exclude extraneous material, this may have been inadvertently collected with the samples. Samples for pollen analysis were extracted from the centre of the cores and are unlikely to be similarly affected. At present it is assumed that the sample was contaminated and will not be used for calculation of deposition rates. The age/depth curve for the Lake Tagimaucia core (Figure 4.9) indicated deposition rates have varied in the past. Inferred ages (i.a.) were extrapolated from the ^{14}C dates. An estimation of fossil pollen influx rates (grains cm^{-2} yr^{-1}) has been made for the major taxa to aid interpretation of the percentage pollen diagrams. Since present day pollen influx values are not available for Lake Tagimaucia, interpretation of the fossil influx values may be possible with reference to data from other tropical forest sites. However, it is emphasized that the values confidently show only direction of change and interpretation must proceed with caution. Inferred ages (i.a.) are indicated on the pollen diagrams beside the stratigraphic column.

Stratigraphy

The stratigraphy of the pollen core is presented in diagrammatic form on the pollen diagram of swamp taxa, Figure 4.10, and described below. The stratigraphic symbols are the same as those on Figure 4.7. Adjacent to the stratigraphic column are the curves of percentage moisture and loss on ignition.

0 - 10 cm	A mat of surface algae which is highly organic and was saturated at the time of collection.
10 - 260 cm	Very fibrous fresh brown sedge peat with well-preserved sedge roots throughout. Both moisture and estimated organic content are consistently high, 80 to 90% and 96 to 98%, respectively.
260 - 340 cm	The peat becomes more humified (i.e. blackened and homogeneous) at these depths and between 280 and 320 cm it is mixed with gritty material which is probably volcanic ash. Organic values are much reduced in this layer (25 to 50%) and moisture values are slightly lower.
340 - 950 cm	The peat is replaced by a red/brown homogeneous lake mud with abundant fragmented wood and sedge shoot and root inclusions. The material becomes darker in colour with depth and banding occurs from about 775 cm. Organic content steadily increases throughout this stratigraphic unit from 60 to 70% at the top to 98% at the base. Percentage moisture values fluctuate, but are generally between 75 and 80%.
950 - 1325 cm	The banding noted above continues down the core but there is an increasing abundance of clay with depth. As a consequence, organic values are lower towards the base, averaging about 60%. Moisture content remains consistently high.

Figure 4-10: Lake Tagimaucia: Percentages of Swamp Taxa



For stratigraphic symbols see Fig. 4.7

4.4.3 The Swamp Pollen Diagrams

The swamp pollen percentage diagram

The percentage pollen diagram of swamp taxa from Lake Tagimaucia is presented on Figure 4.10. It includes the stratigraphy, sediment determinations and local swamp pollen types which have been excluded from, but calculated on the basis of the dryland pollen sum of 200 grains. The swamp pollen diagram has been divided into 6 zones (TA to TF), based upon changes in frequency of the major pollen taxa. These subjectively determined zones are for description and analysis only and are not representative of a regional zonation. Changes in taxa which characterise the zones are described below.

TF 1320 - 1220 cm (i.a. 14 100 - 13 100)
Swamp pollen taxa are uncommon in these basal sediments and values for all taxa are low or absent. *Freycinetia* is the only taxon with consistent representation.

TE 1200 - 1100 cm (i.a. 13 000 - 12 000)
This zone is characterised by initially high but decreasing values for *Freycinetia*. *Pandanus* also has two high values at the base, but then decreases.

TD 1080 - 740 cm (i.a. 11 900 - 5750)
Lepironia and *Haloragis* sim. have more consistent representation and *Pandanus* increases dramatically in this zone. *Freycinetia* decreases from initially high values.

TC 720 - 280 cm (i.a. 5500 - 1600)
This zone is characterised by extremely high values (often >100%) for *Pandanus* and moderate and consistent values for *Freycinetia*. *Lepironia* comp. has much lower and less frequent representation, while *Haloragis* sim. has two very high values near the top of the zone and low representation throughout the remainder.

TB 260 - 200 cm (i.a. 1600 - 1100)
The base of this zone is characterised by a sharp decrease in the representation of *Pandanus*, *Freycinetia* and *Haloragis* sim. and a sudden increase in *Lepironia* comp. and *Eleocharis* comp.

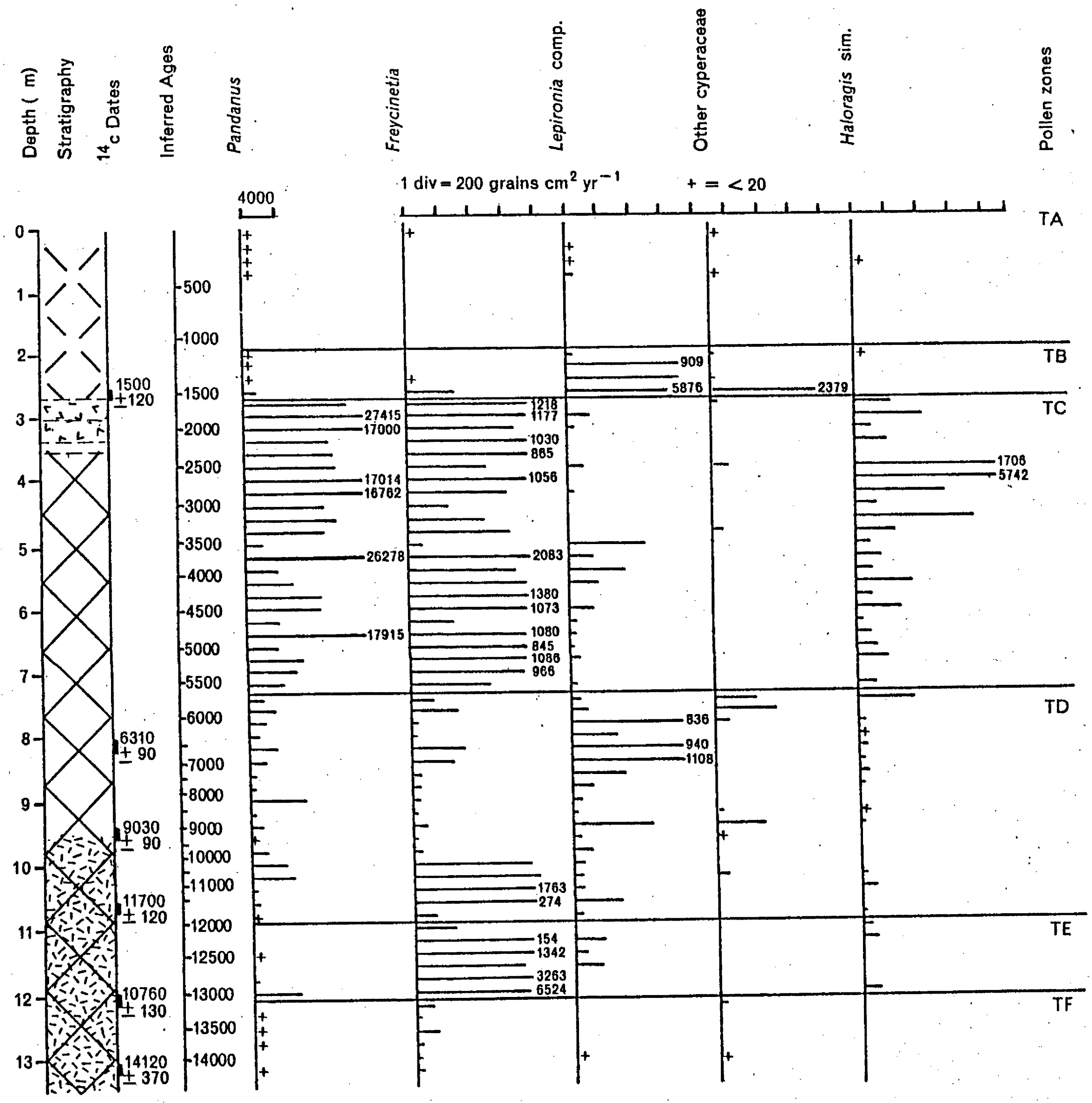
TA 180 - 0 cm (i.a. 1000 - 0)
Both *Lepironia* comp. and *Eleocharis* decrease at the zone TA/TB boundary and none of the swamp taxa are well-represented in the pollen spectra of this zone.

The swamp pollen influx diagram

The estimated pollen influx values (grains cm^{-2} year^{-1}) of combined swamp pollen taxa and selected individual taxa are presented on Figure 4.11.

Pollen influx values for swamp taxa are relatively low below about 800 cm. *Freycinetia* has the highest individual influx at these depths, although values decrease dramatically above 1000 cm. *Lepironia* comp. has increased influx values above this. Total swamp pollen influx values increase substantially above 800 cm, largely due to the very high pollen influx of *Pandanus* and repeated high influx of

Figure 4-11: Lake Tagimaucia: Pollen Influx of Swamp Taxa



For stratigraphic symbols see Fig. 4.7

Freycinetia. *Haloragis* sim. has a similar rise in influx values. Cyperaceae contribute little to the pollen influx except for some isolated high values between 300 and 200 cm. Swamp pollen influx is again very low above 260 cm.

4.4.4 The Dryland Pollen Diagrams

The dryland pollen percentage diagram

The percentage pollen diagram of dryland pollen taxa and pteridophytes is presented on Figure 4.12, which also includes the stratigraphic column, ^{14}C dates and inferred ages of the pollen core. The percentages are calculated on the basis of the pollen sum of 200 dryland pollen grains; the pteridophyte taxa are excluded from the pollen sum, but their percentages are calculated on the same basis. The diagram has been divided into six local zones (T1 to T6). The zone boundaries are based upon changes in major pollen contributors as well as indicator taxa as follows.

T6 1320 - 1220 cm (i.a. 14 100 - 13 100)

This zone is characterised by a peak in *Podocarpus*. The other rainforest gymnosperms, *Agathis* and *Dacrydium*, have low but their most sustained values in this zone. *Ascarina* has high representation, and *Bischofia* increases towards the top. Other common taxa include *Balanops*, Arecaceae, Cunoniaceae, *Rapanea*, and Urticaceae type 1. Pteridophyte taxa are represented by Cyatheaceae and *Lycopodium*.

T5 1200 - 960 cm (i.a. 13 000 - 9500)

The base of zone T5 is defined by much reduced values for *Podocarpus*, increased values for *Balanops*, Arecaceae, *Quintinia* comp., Leguminosae, Myrtaceae types 1 and 2, and *Lycopodium*. *Coprosma* has its most sustained representation for the sequence in this zone. Cunoniaceae and *Rapanea* have sustained representation from zone T6, while *Dacrydium* and *Agathis* virtually disappear from the record.

T4 940 - 820 cm (i.a. 9100 - 6500)

The zone T5/T4 boundary is characterised by a reduction in *Ascarina*, Cunoniaceae, *Quintinia* comp. and Urticaceae 1, while Arecaceae, *Omalanthus* and *Calophyllum* increase slightly.

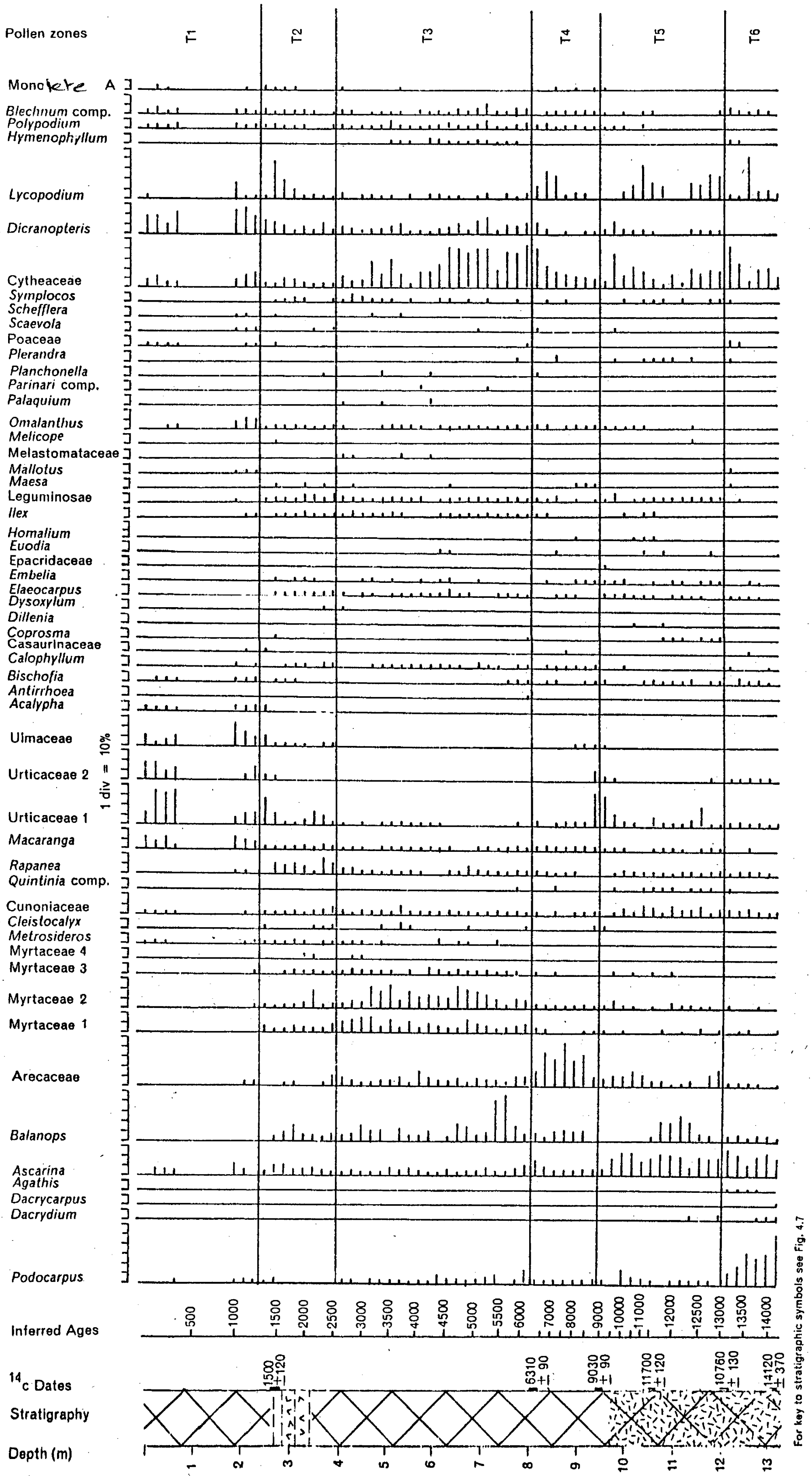
T3 800 - 420 cm (i.a. 6300 - 2900)

The base of this zone is marked by a decline in Arecaceae, the virtual disappearance of *Quintinia* comp. and *Coprosma* from the record and an increase in all myrtaceous taxa, which then peak in this zone. *Balanops* generally declines towards the top of T3 while *Ilex*, *Calophyllum*, Cunoniaceae and *Plerandra* are common throughout. Cyatheaceae has very high values and *Dicranopteris*, *Polypodium* and *Blechnum* comp. increase, while *Lycopodium* declines in importance.

T2 400 - 260 cm (i.a. 2800 - 1600)

In zone T2 the myrtaceous taxa decline and then disappear at the top; Arecaceae also becomes even less common than in zone T3. *Rapanea*, Urticaceae 1 and Ulmaceae show an overall increase. Cyatheaceae has reduced values and *Lycopodium* is the most common of the pteridophytes.

Figure 4-12: Lake Tagimaucia: Percentages of Dryland Taxa



T1 240 - 0 cm (i.a. 1400 - 0)

> The surface zone is marked by the virtual disappearance of *Balanops*, Arecaceae, Myrtaceae, Cunoniaceae, *Rapanea*, *Calophyllum*, *Elaeocarpus*, *Embelia*, *Plerandra* and *Symplocos* from the record. Very high values are displayed by *Macaranga*, Urticaceae types 1 and 2, Ulmaceae and *Acalypha*, and initially high but decreasing values for *Omalanthus*. These trends continue to the surface. The pteridophytes are well-represented by *Dicranopteris* and there is a sustained presence by the remaining pteridophyte taxa.

The dryland pollen influx diagram

The estimated pollen influxes of selected dryland taxa are shown on Figure 4.13.

The fluctuations in influx values broadly correspond to the zonation presented above in Figure 4.12, so these zones have been included in the diagram.

Total dryland influx is low in the basal zone T6, with highest values for *Podocarpus* and *Ascarina*. All values increase dramatically above the zone T6/T5 boundary, especially *Ascarina*, *Balanops*, Arecaceae, Myrtaceae and Cunoniaceae. *Dacrydium* has its highest influx values for the sequence in the lower part of T5, and virtually disappears from the record above this. Most dryland pollen influx values decrease in T4, except Arecaceae. Influx values again increase in zones T3 and T2, especially *Balanops*, Myrtaceae, Cunoniaceae, *Rapanea*, *Calophyllum*, *Elaeocarpus*, *Ilex*, *Omalanthus*, *Plerandra* and *Symplocos*. Urticaceae 1 increases in T2.

There are high influx values for Cyatheaceae and *Lycopodium* throughout zones T5 to T2; *Dicranopteris* and *Blechnum* comp. are more common in T3 and T2.

All dryland pollen influx values decrease substantially in zone T1.

4.5 Discussion

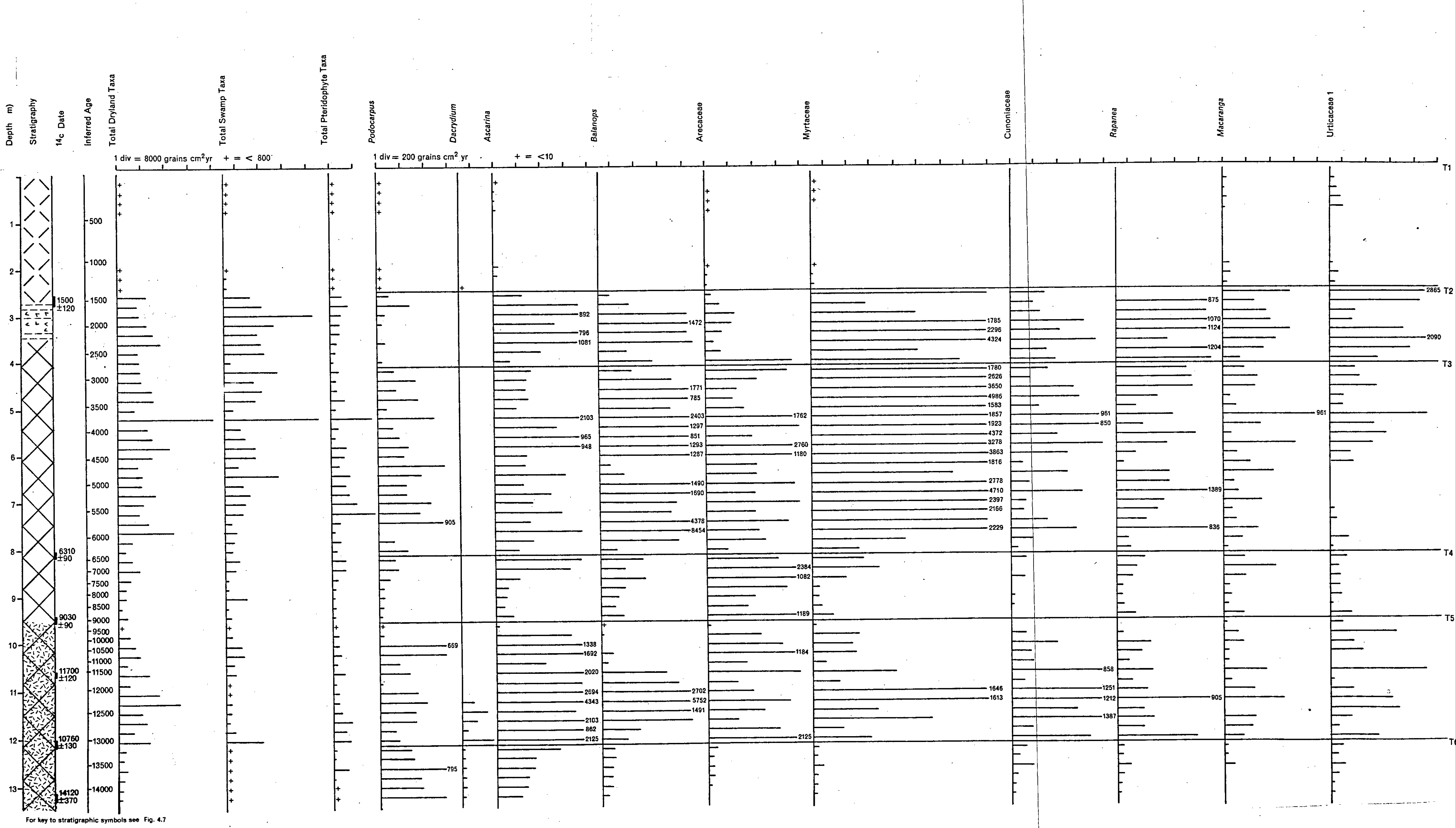
4.5.1 Development of the Swamp and Local Vegetation

The wetland vegetation at Lake Tagimaucia is represented by few pollen taxa in the fossil assemblages. *Pandanus* and *Freycinetia* are the most commonly occurring types, with erratic representation by *Lepironia* comp. and *Eleocharis* comp. The present day swamp flora at Lake Tagiumaucia is composed largely of these taxa and the only other common taxa (e.g. *Rhynchospora corymbosa*, *Mikania micrantha* and *Polygonum dichotomum*) are european introductions. Therefore this small number of wetland taxa is to be expected.

The basal sediments in the pollen core and the stratigraphic cores from the

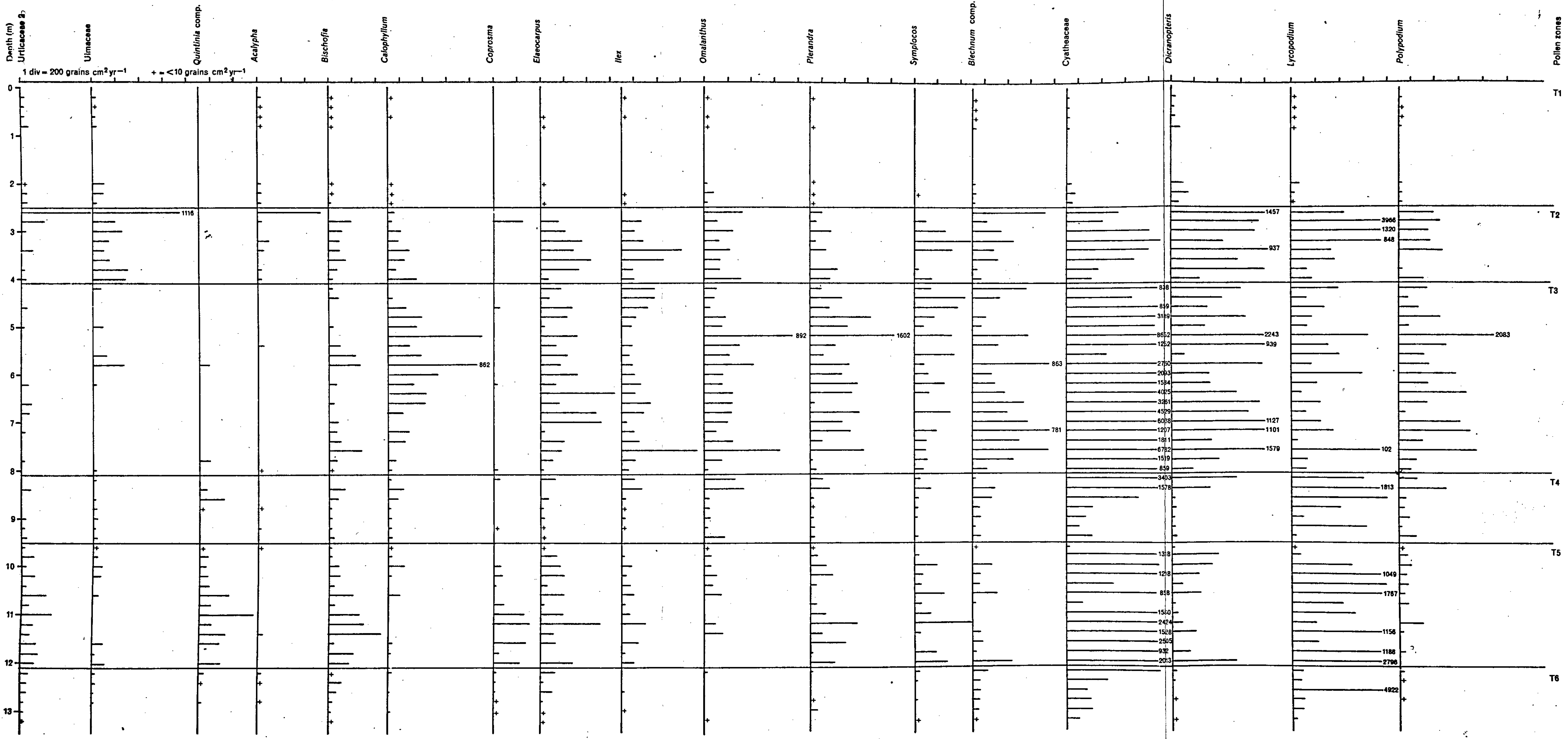
[redacted]

Figure 4-13: Lake Tagimaucia: Pollen Influx of Dryland Taxa



For key to stratigraphic symbols see Fig. 4.7

Figure 4-13 cont'd



centre of the basin are homogeneous mealy red/brown muds similar to the present lake bottom muds. This suggests that open water conditions were much more extensive at 14 000 BP than at present. The pollen spectra from the swamp taxa substantiate this interpretation of the stratigraphy to some extent. At the base of zone TF the swamp taxa are poorly represented with low percentages and influxes for *Freycinetia* only. Given that open water conditions were probably extensive at this time and the steepness of the slopes rising from the basin, areas suitable for swamp vegetation would have been severely restricted and low representation of swamp taxa likely. Since both Pandanaceae and Cyperaceae pollen are probably at least partly water-borne, their absence from the lake muds suggests that neither of these communities was present at the lake margins at 14 000 BP. Unfortunately, there are no modern analogues in the surface samples for this situation. The modern lake is completely surrounded by swamp vegetation, dominated by either Pandanaceae or Cyperaceae, and the interpretation of the basal swamp pollen spectra remains speculative. The *Freycinetia* pollen which is present may be derived from forest vegetation at the lake edge and water-borne to the site.

There is some inorganic banding evident in the sediments at these depths. If there was little or no fringing swamp vegetation at the time to form a protective filter for the lake, then these bands may represent slope run-off directly into the basin.

From the base of zone TE, there is more consistent representation of swamp taxa. *Pandanus* pollen is present, which suggests it became established as a fringing community from about 13 000 BP. Pollen influx for *Freycinetia* is high in this zone, perhaps because it moved as an epiphyte with the *Pandanus*.

Swamp communities apparently became even more widespread and firmly established during the period from about 11 900 to 1600 BP, covered by zones TD, TC and TB. The extremely high percentage values for *Pandanus* are indicative of a lake edge community, probably almost completely surrounding the swamp. Increased representation by *Lepironia* comp. in zone TC may indicate some expansion of peat swamp near the lake edge, most likely as an understorey to the expanding *Pandanus* community, rather than as an expanse of sparse *Lepironia* swamp such as occurs at present. If the latter suggestion was valid, then it would be expected that much of the *Pandanus* pollen would never be transported to the pollen site, because there would be no direct water access between the *Pandanus* community and the lake. This is obviously not the case. *Freycinetia* is reduced in this zone, which may be the result of some filtering of pollen by the *Pandanus* fringe. This could mean that the *Freycinetia* was a component of the nearby forest and the *Pandanus* community itself.

In zone TC, from 5500 BP, *Lepironia* comp. is much reduced in the pollen assemblages, while *Pandanus* maintains its representation. *Haloragis* sim. is consistently present and is abundant in at least two samples. The changes in the pollen spectra are perhaps indicative of the development of fringing swamp communities similar to the present situation; that is the encroachment of peat swamp into the lake, supporting a sparse *Lepironia*/algal community. It might be expected that the *Lepironia* comp. values would remain high because it so often forms a thick, productive fringe at the present swamp margin, but this is not so. Neither does *Pandanus* show any reduction, so it is likely that a *Pandanus* dominated community continued to fringe the lake in at least some part of the basin.

Throughout the basal zones the environment of deposition at the pollen site is consistently open water. The changes in the swamp pollen spectra reflect variation in swamp communities at the lake margins. This situation alters above the zone TC/TB boundary at about 1600 BP, where a layer of volcanic ash separates the lake muds below and the sedge peat above. The environment of deposition is dramatically different and suggests an abrupt transformation from an open water situation to a peat swamp. Notably such a change would alter the mode of pollen transport to the core site from a combination of air- and water-borne extralocal and regional pollen types, to air-borne extralocal and regional types plus *in situ* deposition by local pollen producers. The swamp pollen spectra change accordingly. *Pandanus* and *Freycinetia* virtually disappear from the record, and there are high values for *Lepironia* comp. and *Eleocharis* comp. The absence of both *Pandanus* and *Freycinetia* may thus be a reflection of the probable diminution of the water-borne component of the pollen rain, and the expansion of sedge swamp to completely surround the lake.

In zone TA the representation of all swamp taxa is diminished, which perhaps suggests that the pollen site was occupied throughout this period by the sparse *Lepironia*/algal community which persists there at present.

A tentative explanation of the upper changes in the stratigraphy of the southern part of the Tagimaucia basin was presented above in section 4.3. The swamp pollen spectra in these sediments appear to substantiate the explanation. An expansion of *Lepironia* swamp across the lake basin and past the pollen core site would be expected to have abundant *Lepironia* growing at the leading edge, and behind this edge, where productivity is much lower, a sparse *Lepironia*/algal community would be anticipated. The high values for *Lepironia* comp. and *Eleocharis* comp. in zone TB may be representative of a prolific sedge community at the swamp margin as it encroached into the lake. The reduced values in zone TA are perhaps indicative of a sparse *Lepironia* community such as exists on the bulk of the Lake Tagimaucia swamp at present. The much higher productivity at the swamp margin suggests that lateral expansion would be far more rapid than vertical peat accumulation. Thus it is distinctly possible that minimal upward growth of the swamp has occurred since the initial swamp expansion.

If this hypothesis is correct, the lake deposits would continue to slowly accumulate until the incursion of swamp vegetation occurred. Deposition of peat would then have progressed sequentially across the swamp surface, so that at a given depth in the deposit older peat would be near the basin slopes and younger peat near the lake edge. In an attempt to test this, two short cores were collected from a small embayment of the basin and another core was collected from a location near the original dated pollen core, but closer to the slopes (see Figure 4.6). The material at 150 cm in each core was ^{14}C dated. The stratigraphy and ^{14}C results are shown on Figure 4.14.

It should be noted that cores T3, T4 and T5 were collected 12 months after the deeper sediments, in November 1984, when there had been a period of three months heavy rainfall. The level of the swamp near the swamp margin was raised by about 1 m at this time and the water in the cores above the ash horizon is probably a reflection of these conditions. The evidence suggests that the water which flows under the sedge peat after heavy rain is restricted to these horizons. There was no indication in any of the stratigraphic cores that the water flowed through the lake muds. This implies that some disturbance of the lower sedge peats may have taken place and younger material (including pollen) deposited there. This may partly explain the very high percentage and influx values for Cyperaceae in zone TB. It may also mean that the date of 1500 BP from just above the ash horizon is too young. However, since the date coincides with dated volcanic activity elsewhere in Taveuni, it may be that the total input of younger carbon from the water is insignificant.

If 1500 BP is used as a chronologic datum for the sediments immediately above the ash fall, then the dated samples at 150 cm in cores T3, T4 and T5 may be used to extrapolate deposition rates for the lower sedge peats. These range from 3.2 cm 100 yr^{-1} (core T4) to 6.7 cm yr^{-1} (core T5), and are similar to rates of accumulation in the underlying lake muds. The rates of accumulation above the dated horizons are much higher.

Cores T4 and T5 were collected about 100 m apart and the dates suggest that in approximate terms 100 m of swamp encroachment took place in about 300 years,

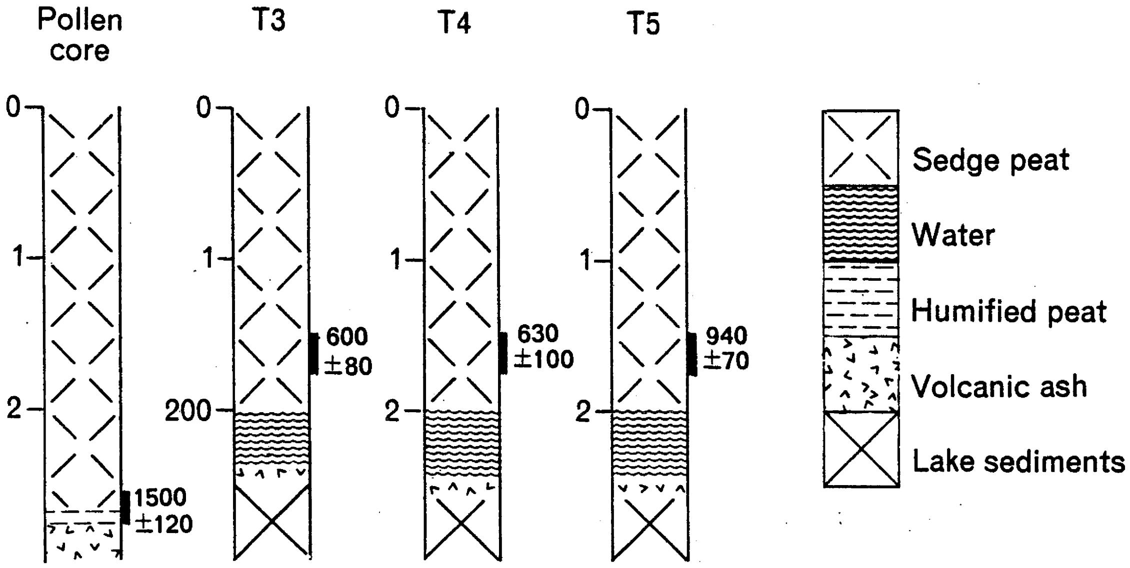


Figure 4-14: Stratigraphy and Dates of Short Cores

compared with about 50 cm of upward growth in the same period in core T5. This corresponds with the sequence of peat expansion derived from the biomass estimates given above, but the accumulation rate apparently remains high until the present, which was not expected. The lake edge community with high productivity is at some distance from the core sites and deposition rates would be expected to slow, as nutrient supply diminished.

Basin morphology indicates that the level of the swamp surface may be controlled by the level of the outflow channel, although detailed surveying would be necessary to confirm this. It appears that once this level is reached, further upward accumulation slows considerably and possibly ceases. The dates suggest that accumulation is relatively rapid once the sedge swamp is established at any particular point in the basin as was indicated by the swamp biomass estimates. Such a situation might account for the very low pollen influx values in the upper samples, in that the surface may not represent the present and therefore each sample represents fewer years of upward growth. However, raising the pollen influx values to a level which would be expected for a site surrounded by closed forest involves increasing the deposition rate almost tenfold, suggesting the surface level at the pollen site was achieved about 1000 years ago. It would then be expected that the surface samples would have a very high concentration of pollen, which is not evident, but the very opposite (i.e. very low pollen concentrations) is the case.

It is more likely that the apparent reduction in pollen influx is the result of a combination of factors. Firstly, deposition rates were probably rapid and the surface reached sometime in the past, although not as much as 1000 years ago. Secondly, a fall of ash onto the landscape would have had a profound impact upon the vegetation, such that pollen production may have been much reduced, at least temporarily. Thirdly, the change in depositional environment from open water to peat swamp conditions eliminated the water-borne component of the pollen influx, and it may well be that this is the most significant component of the total pollen influx at Lake Tagimaucia. Pollen influx from rainforest has long been suspected to be extremely low (Faegri 1966; Kershaw and Hyland 1975; Flenley 1979a) and the data from Lake Tagimaucia seem to provide further agreement.

4.5.2 Development of the Dryland Vegetation

Taveuni occupies a relatively isolated position in the south-west Pacific. Long-distance dispersal of pollen to Lake Tagimaucia is thus likely to be infrequent, especially since the prevailing south-east winds have travelled exclusively over ocean. During the months of October to April, when more variable winds from the north may be experienced, it is possible that some pollen may be wind-borne from a great distance to the site, but while long-distance pollen transport may be significant in remote areas with sparse vegetation (e.g. Macquarie Island; Salas 1983), this would form a negligible part of the total pollen rain in a rainforest situation. The only taxon in the surface samples which was probably representative of dispersal from other islands in the group was *Dacrydium* and this was present in only minimal quantities (see Chapter 3).

Kershaw and Hyland (1975) and Grindrod (1979) demonstrated that a regional component was present in the pollen input to Lakes Euramoo and Eacham, located within marginal rainforest, but they considered that this component would be less significant at lakes in tropical rainforest, such as Lake Tagimaucia. The modern pollen rain discussed in Chapter 3 indicated there was very little lateral movement of pollen in the forests of Taveuni and the regional component of the pollen rain probably consisted of a very few taxa. In the discussion of swamp development and local vegetation above (section 4.5.1) it was intimated that much of the pollen input to the Lake Tagimaucia basin was water-borne. It is likely then that the dryland vegetation record contained within the sediments of this site will be one of changes largely within the catchment.

The fossil pollen influxes to Lake Tagimaucia were estimated for the major taxa. There are no modern influx values for Lake Tagimaucia available at present, so interpretation of the influx values must depend upon work carried out elsewhere.

Tropical rainforest pollen influx has been shown to be quite low compared with values from temperate regions. This is largely because many rainforest taxa are entomophilous, wind velocities are low, which, coupled with dense vegetation growth, means that little pollen is transported away from the immediate vicinity of the parent plants. The most comprehensive analysis of forest pollen influx in a tropical situation has been done on the montane forests of Papua New Guinea (Hope 1976; Walker and Flenley 1979). It is concluded that pollen influx values must consistently exceed 4000 grains cm^{-2} yr^{-1} for closed forest to have surrounded and overhung the pollen site. Values between 2000 and 4000 grains cm^{-2} yr^{-1} require careful interpretation, and values less than this may indicate substantially unforested conditions near the sampling site and up to 70% of the pollen may be from distant sources. Although these values were obtained from more pollen productive high montane forests, they will be tentatively used as a guide to interpretation of the Lake Tagimaucia record.

The pollen dispersal and representation characteristics of the major dryland taxa in the modern pollen rain in Fiji were summarised above in Table 3.2. Coupled with the pollen influx information summarised above, this forms the basis for interpretation of the Tagimaucia pollen diagrams.

The estimated total pollen influx for dryland taxa in the basal sediments is well below 4000 grains cm^{-2} yr^{-1}, and often below 2000. This probably indicates that a substantial lake separated the forest from the sampling site, and much of the pollen may be from regional sources. The taxa which dominate the pollen spectra in zone T6 (*Podocarpus* and *Ascarina*) are probably components of a regional pollen rain, as the surface samples imply, and they are also known for their good pollen dispersal potential elsewhere in the region (McGlone and Moar 1977; Walker and Flenley 1979). It is possible that they represent vegetation communities both within and outside the catchment. Taxa which are also present, but unlikely to be representative of distant transport include *Dacrydium*, *Dacrycarpus*, Cyatheaceae and *Lycopodium*. The basal sediments are characterised by inorganic bands and moderately high inorganic content, which may simply be the result of slope-wash into the lake with no filtering from fringing swamp vegetation, but slightly more open forest in the catchment may also be indicated.

The dryland pollen spectra in zone T6 are unlike any of the modern pollen samples described in Fiji, or any of the more recent samples in the Tagimaucia core. Given the severity of environmental conditions at this time elsewhere in the Australasian region, reviewed in Chapter 1, it is likely that the vegetation throughout Fiji was quite different from the present. The pollen spectra and influxes are tentatively interpreted as indicating that a slightly less dense forest vegetation prevailed on Taveuni. It may have been composed of *Ascarina* with emergent gymnosperms and perhaps an understorey of treeferns.

A vegetation community with both *Ascarina* and gymnosperms was not observed anywhere in Fiji at present, but the genera are found together in the mixed Podocarp-hardwood vegetation communities in New Zealand. These are most common in upland North Island and lowland Westland in the South Island (Godley 1975) where climatic conditions include high average annual rainfall (>1600 mm, rising to >3200 mm in Westland), low evaporation, and mild temperatures with few frosts (Coulter 1975; McGlone and Moar 1977). The modern pollen spectra from these forests (Moar 1970; Pocknall 1978, 1980; McGlone 1982) did not correspond with the zone T6 Tagimaucia pollen spectra, but the representation of *Ascarina*, *Podocarpus*, treeferns and, to a lesser extent, *Dacrydium*, is remarkably similar in early to mid-Holocene samples from many New Zealand pollen sites (McGlone and Moar 1977). These early to mid-Holocene pollen spectra are interpreted as indicating the expansion of Podocarp-hardwood forests beyond their present limit as a response to marginally warmer conditions, with perhaps a 30% increase in precipitation (McGlone and Moar 1977; McGlone 1983b).

In Fiji *Ascarina* is restricted to small areas at the highest elevations, suggestive of a preference for cooler conditions. Data on the genus *Ascarina* from New Zealand (McGlone and Moar 1977) and Papua New Guinea (Walker and Flenley 1979) suggest it is not frost-tolerant, but flourishes where the mean annual temperature is between 9 and 22°C. The gymnosperm taxa are most common in Fiji in areas with drier and more seasonal rainfall regimes than occur at present. Combining these data suggests that substantially cooler and at least seasonally drier conditions prevailed near Lake Tagimaucia between 14 300 and 13 000 BP. Precipitation may have been reduced by at least 50% of present values at 14 000 BP on Taveuni. In central Taveuni, where present precipitation is high and non-seasonal in distribution, more seasonal rainfall is likely to have had a more significant impact on the vegetation patterns than simply an overall decrease in rainfall.

Although temperatures lower than present are implied by the presence of *Ascarina*, the degree of temperature reduction is difficult to assess. *Ascarina* usually occurs in the ridge and mountain top forests which are restricted to the cooler areas above 1000 m asl (Smith 1981). If this altitudinal limit was reduced to 700 m at 14 300 BP, and using the lapse rate of 6.4°C 1000 m^{-1}, then mean temperatures were at least 2°C lower than present. However, the pollen taxon most characteristic of these forests at present is Cunoniaceae, which is not abundant in the zone T6 spectra. It is possible that the greatest development of this vegetation community was at even lower elevations than Tagimaucia between 14 300 and 13 000 BP and that temperatures were reduced by more than 2°C at this time.

Above the zone T6/T5 boundary, from about 13 000 BP, there is a dramatic increase in pollen influx values for many dryland taxa; the dryland influx is consistently greater than 4000 grains cm^{-2} yr^{-1}. There is little doubt that closed forest surrounded the pollen site. In the percentage diagram, zone T5 is characterised by continued high representation of *Ascarina*, increases in *Balanops*, Arecaceae, Myrtaceae, Cunoniaceae, *Quintinia* comp. and *Coprosma*. This pattern is repeated to a certain extent in the influx diagram; however, the behaviour of *Podocarpus* in influx terms is markedly different. *Podocarpus* maintains consistent influx values across the zone boundary; those taxa which show increased representation in percentage terms all dramatically increase on the influx diagram. This suggests that while *Podocarpus* maintained its representation in the surrounding vegetation, other taxa were simultaneously able to move into the area.

If most of the pollen input to Lake Tagimaucia is water-borne then the dramatic increase in the influx of those taxa mentioned above, and to a lesser extent *Elaeocarpus*, *Ilex*, *Plerandra* and *Symplocos*, may indicate that they had expanded into the Lake Tagimaucia catchment from 13 000 BP, perhaps from lower elevations. The data suggest that most of the taxa arrived simultaneously.

The taxa common in zone T5 generally occur together in the ridge and mountain forests, although without *Podocarpus* (Smith 1981, 1985), and except *Quintinia* which has not been recorded from Fiji, but elsewhere in the south-west Pacific region is indicative of relatively cool climates. The presence of such a community in the Lake Tagimaucia catchment implies that conditions were cooler than present between 13 000 and 9000 BP, but its apparent movement upward to take up this position may represent a response to warming from an even colder preceding period.

Microclimatic data from this community on Des Voeux Peak (Ash in prep. a) are instructive. The figures suggest that cooler temperatures than would be expected from the lapse rates are maintained by the virtually continual cloud cover at these elevations. Since this community is most common on ridge-tops which experience conditions similar to those prevalent on Des Voeux Peak, the indicated presence of ridge forest in the Tagimaucia pollen diagram from 13 000 BP might be interpreted in terms of the prevailing conditions in extant ridge forest. The importance of continual cloud cover in characterising the environmental parameters of this vegetation type should be stressed. Without this phenomenon, the opportunity for transpiration would be increased on the ridge-tops and presumably the vegetation would be comprised of different taxa. It is possible, therefore, that the forests near Lake Tagimaucia at about 13 000 BP were present because of increased cloud cover. With an overall reduction in temperature and a lowered sea level at this time, it is likely that the cloud base over the high islands occurred at a lower elevation. Some of the higher Fijian peaks (e.g. Des Voeux Peak) may have been emergent above the cloud at this time.

As was noted above, this vegetation community was not present during the preceeding period (i.e. 14 300 to 13 000 BP). It is possible that potential precipitation in the immediately post-glacial period was reduced to the extent where orographic uplift did not generate the extensive cloud layers characteristic of high islands in the south-west Pacific. These may have developed only when precipitation had increased. Or alternatively, the cloud base was even lower than Lake Tagimaucia at this time. The continued presence of *Podocarpus* is puzzling since non-seasonal conditions are implied by the occurrence of cloud forest. Possibly the pollen was derived from lower elevations where more seasonal conditions continued to prevail.

Balanops is also common in both influx and percentage terms between 13 000 and 9000 BP. It is a widespread taxon in the Fijian situation, represented by one species, *B. pedicillata*; which is widespread at all elevations, but is nowhere common (Smith 1981). It is thus of little interpretative value in environmental terms. *Balanops* may have been growing anywhere on Taveuni, although the abrupt increase in influx after 13 000 BP strongly suggests its presence in the catchment forests.

The fluctuating values for the forest ephemerals *Macaranga*, Urticaceae and *Bischofia*, with very high values for Cyatheaceae and *Lycopodium* throughout zone T5 may indicate continued periods of disturbance on the catchment slopes. A relatively high inorganic content at these levels may support this suggestion. The most likely forms of disturbance on Taveuni during the late Quaternary are landslips following minor earth tremors. Such disturbances have occurred during historical times. Following the tremors, large areas of bare soil are exposed, especially on the very steep slopes in central Taveuni where the water-logged, friable soils are inherently unstable if disturbed. These areas show up as scars in the forest and are quickly colonised by *Lycopodium*, *Dicranopteris*, then treeferns (Cyatheaceae), palms (Arecaceae) and the forest ephemerals (Urticaceae, Ulmaceae and *Macaranga*).

At about 9000 BP (the T5/T4 boundary) most of the taxa indicative of cooler conditions and *Podocarpus* and *Dacrydium*, which were common in zone T5, show reduced representation and influx. It is possible that both temperature and precipitation approached their present means and annual distribution. The pollen spectra suggest the gradual development of the forests to their present composition and diversity from this time. However, while some taxa do show increasing influxes, the total dryland pollen influx values are again reduced to similar levels as in zone T6. The only taxa to maintain their pollen deposition are Arecaceae, *Macaranga*, *Omalanthus*, and amongst the pteridophytes, *Blechnum* comp., *Lycopodium* and *Polypodium*. Many of these taxa are forest ephemerals and anemophilous. The figures may suggest that the forest was again more open, perhaps as a response to environmental upheaval, which may include major tectonic activity in the area. A major landslide near Lake Tagimaucia may have resulted in the temporary precedence of ephemeral taxa in the dryland vegetation. However, the pollen influx of these taxa is similar to zone T6 and therefore probably did not increase in importance in the catchment vegetation.

On the other hand, the swamp pollen spectra and influxes at this time are indicative of the development of extensive surrounding peat swamp at Lake Tagimaucia. This may have reduced the amount of dryland pollen being water-borne from the slopes to the pollen site at this time and the anemophilous taxa would be better represented in the pollen spectra. It would be expected in this case that the pollen influx values of these taxa would be maintained. The highly organic nature of the lake muds at these levels may have resulted from the filtering of slopewash by the surrounding swamp vegetation. This explanation seems most likely if the dryland vegetation and swamp developments are viewed together.

While the pollen spectra in the upper samples of zone T4 suggest changes toward the present forest conditions, the full development of the forest appears to have occurred from about 6300 BP (the zone T4/T3 boundary). The dryland pollen taxa increase dramatically in diversity. *Calophyllum*, *Elaeocarpus*, *Plerandra*, *Symplocos*, *Rapanea*, *Palaquium*, *Ilex*, and especially Myrtaceae have their greatest influx and representation in zone T3. These pollen assemblages most closely resemble modern pollen samples from sites at moderate elevations on the east coast of Taveuni and suggest that conditions were probably most similar to the present.

The exceptionally high Myrtaceae values are anomalous. Most species of Myrtaceae are insect, bird, or occasionally mammal pollinated (Ford *et al.* 1979; Hopper 1980; Hopper and Moran 1981) and unlikely to produce large quantities of pollen for wind dispersal to a pollen deposition site. The very high values for Myrtaceae in zones T3 and T2 therefore probably indicate a local source for the pollen. The taxa producing the pollen may have been growing along the swamp margins and the pollen was being washed into the site, but at this time the swamp pollen assemblages indicate a well-developed fringing *Pandanus* community was present in the Tagimaucia basin and it seems likely that a large proportion of the Myrtaceae pollen would have failed to reach the pollen core site.

An alternative explanation is that myrtaceous taxa were a component of the swamp vegetation at this time. Although no swamp forest is presently recorded for Fiji, and none of the stratigraphic cores recovered from Lake Tagimaucia suggested deposition under swamp forest, woody fragments were present in the lake muds. Scattered individuals of *Metrosideros* were noted growing in the Lake Tagimaucia swamp and species of Myrtaceae are common in swamp forests elsewhere in the tropics (Whitmore 1984; Maloney 1985). If swamp forest was growing in the Tagimaucia basin at this time, then it represents a unique development in the Fijian context, and one which no longer exists.

In zone T1, after about 1500 BP, there is a massive reduction in dryland pollen influx to the site, taxa common in zone T2 disappear from the record, and the pollen assemblages are dominated in percentage terms by the forest ephemerals *Macaranga*, *Acalypha*, Urticaceae types 1 and 2 and Ulmaceae. These changes may be largely attributed to the changes in environment of deposition at the pollen site discussed above in relation to swamp development. The massive decrease in dryland pollen influx may simply reflect the absence of a water-borne pollen component to the site. If this is the case, then it is likely that water-borne pollen was the most important component of the fossil pollen input throughout the Tagimaucia record.

If swamp forest was growing at the site throughout zones T2 and T3 then the reduction and virtual disappearance of Myrtaceae in influx terms may reflect the changes on the swamp subsequent to a fall of volcanic ash discussed above. Very rapid encroachment of sedge swamp into the basin and deposition of sedge peat may have overwhelmed and destroyed any existing swamp forest which has not since been able to recover.

The abundance of forest ephemeral taxa in percentage terms is probably a reflection of the fact that many of these taxa are anemophilous and would be advantaged in the pollen samples if the water-borne pollen component was reduced. In addition, the blanketing of the dryland vegetation by an ash fall at this time would have disrupted forest growth and it is likely that the forest ephemerals recovered most quickly. At the present time the forest near Lake Tagimaucia is disrupted by minor landslips, but otherwise shows little disturbance.

4.6 Summary

The fossil pollen data from the Lake Tagimaucia core have been tentatively interpreted in environmental terms. The environmental changes indicated by the stratigraphic and palynologic data have been summarised below in Table 4.4.

One of the most characteristic features of the Lake Tagimaucia record of vegetation change for the past 14 000 years or so is the very high degree of environmental instability which is displayed. The early part of the pollen diagram records changes probably related to post-glacial climatic amelioration. Throughout the period of sedimentation the vegetation is likely to have been further affected by short-term events such as earth tremors and at about 1500 BP (and presumably at times in the more distant past) the vegetation was affected by an ash fall from a nearby volcanic eruption and has since recovered from its impact. Human interference in the area in the past is unlikely and none of the vegetation changes need be attributed to such a cause.

During the period represented by zone T6 (14 300 to 13 000 BP) the pollen influxes and spectra suggest that the dryland vegetation in the Lake Tagimaucia catchment consisted of perhaps more open forest than presently occurs. Gymnosperm taxa were common in the forest with *Ascarina*, and possibly the pteridophyte taxa, Cyatheaceae and *Lycopodium*, forming an understorey, at least in the immediate vicinity of Lake Tagimaucia. This indicates that climatic conditions were likely to have been much drier, especially seasonally so, and cooler than the present. The lake was more extensive at this time and swamp vegetation was restricted.

Subsequent climatic amelioration is indicated in the Tagimaucia dryland vegetation pollen diagrams by quite dramatic changes in the pollen influxes and assemblages. The data suggest that a more diverse and closed forest developed in the Lake Tagimaucia catchment. The common pollen taxa at these levels presently occur at higher elevations than Tagimaucia in Fiji in cloud forests and suggest conditions remained cool relative to the present and probably cloudy. Their absence

Table 4.4: Environmental Changes at Lake Tagimaucia

Period (yrs BP)	Dryland Vegetation	Basin Vegetation	Environmental Conditions
14 300-13 000	Forest with emergent gymnosperms and *Ascarina*. Possibly an understorey of treeferns.	Extensive open water with little surrounding swamp vegetation. Some inorganic sedimentation in the lake.	Cooler than present, more than 2°C reduction, possibly 4°C. Drier - perhaps less than 50% present rainfall and more seasonal distribution.
13 000-9000	*Podocarpus* emergent over mixed angiosperm forest, with cool climate connotations. Some incursions of secondary forest taxa.	Development of fringing *Pandanus* swamp.	Climatic amelioration, but temperatures probably +/-2°C below present. Slow increase in rainfall. Some disturbance in the catchment, possibly earth tremors and landslides.
9000-6300	Mixed angiosperm forest composed of taxa common in the area at present. Continued representation of secondary taxa.	Extensive development of fringing swamp communities, both *Pandanus* and Cyperaceae	Attainment of present climatic conditions. Continued tectonic activity in catchment.
6300-1500	Full development of forest in catchment, similar to the present forest.	Development of myrtaceous swamp forest? Reduction in extent of open water.	Period of environmental stability in catchment.
1500-present	Secondary forest taxa achieve dominance in percentage pollen terms, possibly a response to forest disruption by ash fall. Forest returned to present composition during this period.	Massive expansion of swamp communities into lake basin. Open water restricted and present configuration of basin achieved.	Volcanic activity - fall of ash probably increased nutrient status temporarily and caused expansion of swamp and rapid sedimentation.

in the basal zone may indicate that conditions were substantially cooler and less cloudy from 14 300 to 13 000 BP and may give some indication of conditions at the height of the last glacial in Fiji. The number of taxa adapted to cooler conditions is limited in Fiji mainly because of the relatively low altitudes throughout the islands. While these taxa may have expanded downslope during the glacial period in response to a reduction in temperature, a concomitant reduction in precipitation may have resulted in the absence of a substantial cloud cover to maintain the cloud forests at the elevation of Lake Tagimaucia and above. There was possibly no vegetation community recognizable at present to take its place at higher elevations. This may explain why these taxa appeared later in the Tagimaucia record, that is, as a sustained cloud cover was achieved with increasing precipitation.

The sustained influx of *Podocarpus* throughout zones T6 and T5 suggests this taxon maintained its representation in the vegetation, possibly as a forest emergent above the incoming angiosperm forest taxa. Its presence suggests that while precipitation was probably increasing, seasonal conditions may have prevailed until about 9000 BP, or alternatively, seasonal conditions were maintained at lower elevations and the pollen was derived from these sources. The reduction of *Podocarpus* in zone T4 may indicate the time when annual precipitation in central Taveuni achieved its present non-seasonal distribution. Such conditions would favour the establishment of the mixed angiosperm forest which currently dominates Taveuni's central slopes.

Most of the ridge forest indicators also virtually disappear from the Tagimaucia pollen records at the T5/T4 boundary. It is likely that from this time conditions near Lake Tagimaucia closely resembled the present.

There appears to have been a considerable lag (i.e. until about 6300 BP) before the forest achieved a complexity and composition similar to the present, but this may be related to other factors such as the occurrence of minor earth tremors during this period. Conditions between 6300 and 1500 BP appear to have been relatively stable, in terms of the dryland vegetation communities. Swamp communities expanded in area during this period. At 1500 BP a major disruption in the form of volcanic activity affected both the vegetation and processes in the swamp/lake system.

This record of environmental change is broadly consistent with the pattern of post-glacial vegetation and climatic change evidenced by sites throughout the Australasian region, and this will be discussed at length in the final summary chapter.

CHAPTER 5

THE POLLEN SITES: NADRAU PLATEAU

The Nadrau Plateau lies in the centre of Viti Levu at an average altitude of 915 m, see Figure 5.1. The plateau boundary is defined in the west by the steep slopes which descend to the Sigatoka valley; in the north by the Nadarivatu escarpment which runs parallel to and descends to the northern coastline; and by the tributary valleys of the Wainimala and Navua Rivers to the east and south, respectively. The plateau area forms the divide between the two major drainage systems of Viti Levu - the Rewa and Sigatoka Rivers.

While the plateau itself is largely forested (Figure 5.2), the western boundary is marked by an abrupt transition to the *talasiga* grasslands (Figure 5.3). The putative anthropogenic origin of this vegetation was discussed above in Chapter 2.4.2. It was felt that a palynological investigation of a site near the *talasiga* margin might indicate whether these areas were once forested, and if so, whether deforestation occurred during the 3500 years or so of human occupation in Fiji.

Organic sediments suitable for pollen analysis have accumulated in several of the meandering creek valleys of the Nadrau Plateau, and the largest of these, Nadrau Swamp, located in the headwaters of Nanuku Creek, near Nadrau Village, was chosen for investigation. Its large size compared with other swamps on the plateau and its proximity to the *talasiga* boundary (Figure 5.1) suggested Nadrau Swamp might yield a significant record of vegetation change for this area. A second organic deposit at Wainisavulevu Creek was located about 20 km south-east of Nadrau Swamp within the forested part of the Nadrau Plateau. This site was investigated in an attempt to provide a complementary and comparative sequence of forest vegetation change.

Figure 5-1: Location of the Nadrau Plateau

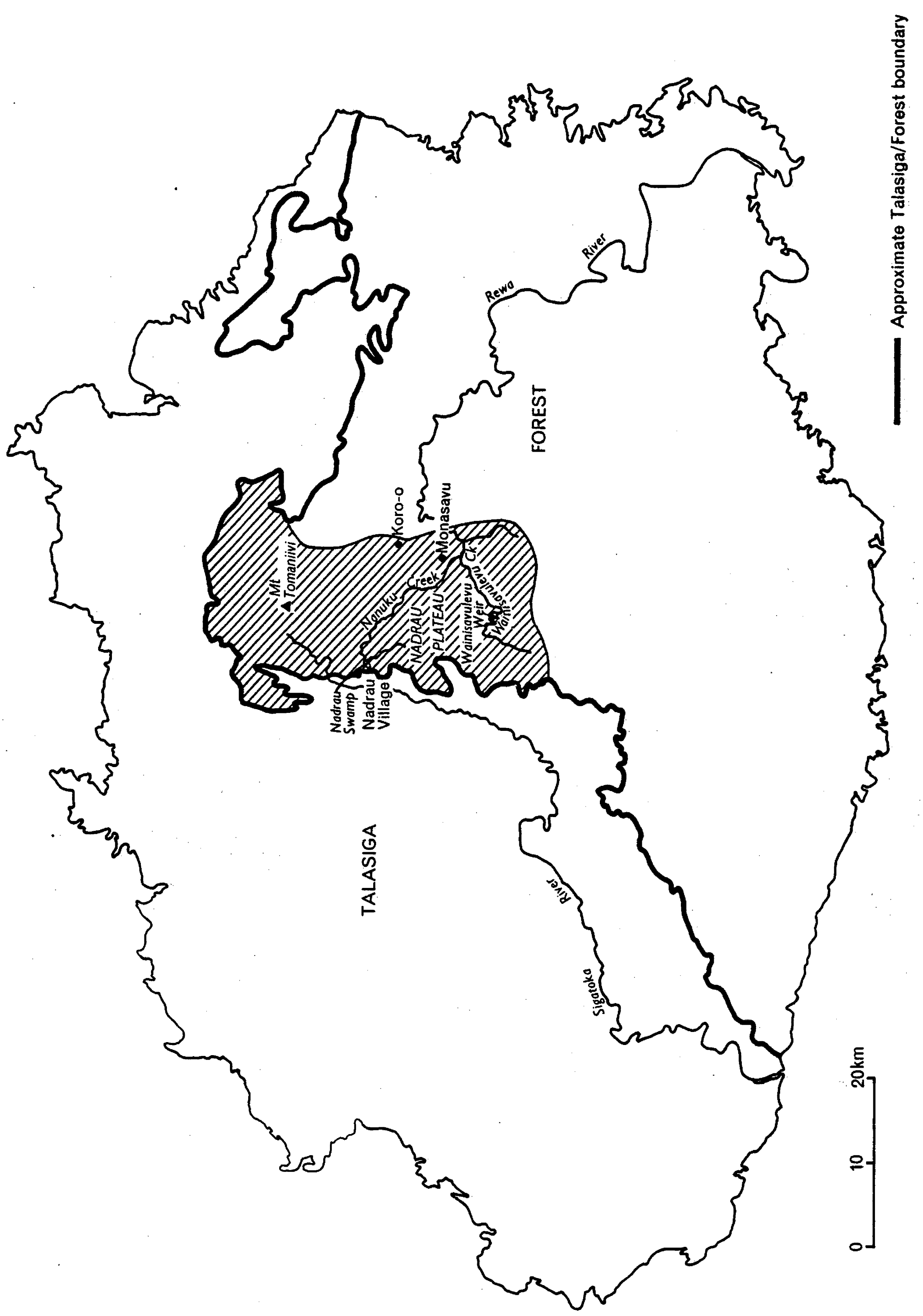


Figure 5-2: Forest Vegetation on the Plateau

Figure 5-3: The *Talasiga* Grasslands

5.1 The Regional Setting: Nadrau Plateau

5.1.1 Geology and Soils

The Nadrau Plateau consists of Pliocene basalts to the north of Nadrau Village and largely basalt derived late Pliocene - Pleistocene sedimentary rocks to the south; all of the Ba Basaltic Group. There is an underlying durable monzonite sill of the Colo Plutonic Suite, probably late Miocene in age, which forms cliffs around the southern margin of the plateau and the beds of most creeks as they leave the plateau. The Mt Tomaniivi Range, including Fiji's highest mountain (Mt Tomaniivi, 1323 m asl), rises as a Pleistocene basaltic conglomerate massif (Geological Survey of Fiji 1966).

The soils which have developed from these rocks in the central plateau area are characterised by formation under a climate with no dry season. The resultant clays and bouldery clays are moderately to highly acid, with varying base status. Some alluvial gley and organic soils have accumulated in the valleys on the plateau (Twyford and Wright 1965).

5.1.2 Climate

The main part of the Nadrau Plateau falls within climatic zone F of Jenkins and Lesslie (1973), characterised by high rainfall and a weak or absent dry season. To the east, south and especially to the north and west, the dry season is more pronounced. Annual and monthly rainfall averages are available from four stations within the region: Nadrau Village (777 m), Koro-O (945 m), Nadarivatu (835 m), and Monasavu (808 m). Together they demonstrate rainfall variation across the plateau. The stations are shown on Figure 5.1 and the rainfall figures are presented in Table 5.1.

Table 5-1: Rainfall Averages for the Nadrau Plateau

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Koro-O	589	653	741	361	114	98	60	132	190	192	240	310	3680
Nadarivatu	567	681	719	336	163	98	82	120	135	136	240	380	3657
Monasavu	606	562	579	513	217	231	138	340	205	421	505	353	4670
Nadrau	636	336	464	242	83	102	77	90	112	144	170	207	2663

(data, in mm, from Fiji Meteorological Service 1981, 1984a, 1984b)

While Koro-O, Nadarivatu and Nadrau show a distinct pattern of wet and dry seasons, rainfall at Monasavu is more evenly distributed throughout the year and is probably representative of rainfall conditions on the southern and eastern part of the Nadrau Plateau. Rainfall decreases sharply to the west and north of the central plateau during the dry season months from May to October; the gradient is much weaker in the wet season. The greatest seasonal variation is displayed by Nadrau, which lies just beyond the western edge of the plateau within the upper

Sigatoka River valley. The change in rainfall regime coincides with the sharp *talasiga* grassland/forest boundary in the region.

Temperatures are relatively cool in the plateau area with annual averages of 19.8°C, 20.3°C, 20.1°C and 20.7°C for Koro-O, Nadarivatu, Monasavu and Nadrau, respectively. Annual variation is about 4°C, while diurnal variation is much higher, about 7°C (Fiji Meteorological Service 1982, 1984a, 1984b).

5.1.3 Vegetation

While the majority of the Nadrau Plateau is under heavy forest cover (type 1A1c, tropical evergreen ombrophilous montane forest), see Figure 5.2, this is replaced by more open forest on the very steep escarpment slopes and by *talasiga* grasslands (Figure 5.3) in the west on the boundary with the Sigatoka River catchment.

The forested areas of the plateau have been enumerated by Berry and Howard (1973) and grouped into forest types which are briefly described below.

1. Areas of flat or gently undulating terrain are characterised by the presence of *Agathis vitiensis* and *Dacrydium nidulum*. Other common taxa are *Calophyllum vitiense*, *C. neo-ebudicum*, Myrtaceae spp., *Metrosideros collina*, *Parinari insularum* and *Heritiera ornithocephala*. The forest typically has a closed canopy 10 to 15 m high with *Agathis vitiensis* emergents to 20 m.

2. Areas of higher elevation and steep, dissected slopes in the northern part of the plateau support a forest of similar composition, but *Dacrydium nidulum* is usually absent.

3. At lower elevations to the south of the plateau the forest is dominated by *Endospermum macrophyllum* and *Parinari insularum* with *Trichospermum* spp., *Degeneria vitiensis*, *Bischofia javanica* and *Dysoxylum richii* and an understorey of *Piper* spp., *Cyathea* spp., *Premna taitensis*, *Alpinia* spp., *Macaranga* spp., *Dillenia biflora*, *Gironniera celtidifolia* and *Hibiscus tiliaceus* The forest is generally 12 to 18 m high.

4. To the south of the plateau, at elevations of 762 to 914 m, there are extensive areas of forest characterised by *Agathis vitiensis*, *Endospermum macrophyllum*, species of Myrtaceae, *Calophyllum* and *Canarium*, with *Podocarpus neriifolius*, *Palaquium* sp., *Dysoxylum richii*, *Parinari insularum* and some *Dacrydium nidulum*. The forest generally has a closed canopy to 20 m high with emergent *Agathis* to 27 m.

5. At higher elevations to the west of Nanuku Creek and the Mt Tomaniivi massif, *Agathis* and *Podocarpus* become more important and are associated with *Dendrocnide harveyi*, *Firmiana diversifolia*, *Geissois ternata*, *Trichospermum richii* and species of Caesalpiniaceae. The overall forest structure is more stunted, shrouded with mosses and lichens and less diverse than those at lower altitudes.

6. The escarpment slopes to the south and east of the Nadrau Plateau are usually covered with an open canopy woodland 7 to 14 m high consisting of *Dysoxylum* spp., *Cananga odorata*, *Alphitonia* spp., *Geissois ternata*, *Dendrocnide harveyi*, *Premna taitensis*, *Endospermum macrophyllum* and *Bischofia javanica*.

The pattern of vegetation variation is similar to that described for Taveuni (see above Chapter 4.1.3). Common taxa at lower elevations are species of Meliaceae, with *Endospermum macrophyllum*, as on Taveuni, although species of *Canarium*, *Parinari insularum* and the gymnosperms feature more strongly in the Nadrau Plateau vegetation. The forest is type 1A1c. At higher elevations the forest is 1A1e and is again characterised by stunting and abundant epiphytes, commonly with species of Cunoniaceae.

5.1.4 Human Impact

Little is directly known of the prehistory of the Nadrau Plateau region, however several inferences are made from the present landscape and it is the intent of this research to elucidate at the least the possible influence of man on the vegetation.

The *talasiga* grasslands to the west of the Nadrau Plateau are ascribed to human activity, including clearing and burning. While this may be so, there are no dates for the period of clearing on Viti Levu. Ash (in prep. b) has tentatively suggested that the burial and death of near shore coral platforms by fine sediment off the north-west coast of Viti Levu at about 3000 BP was a result of clearing and erosion inland. The synchroneity of this event in two catchments suggests a common cause which may well have been human activity.

Berry and Howard (1973) note that several abandoned village sites and gardens, identified by the presence of secondary vegetation communities, are located just within the forest boundary along the western edge of the Nadrau Plateau. Again there are few clues as to the antiquity of the settlements. Within the densely forested parts of the plateau there is little evidence for human occupation prior to the arrival of Europeans and the gradual incursion of tracks and ultimately roads. Several walking tracks cross the plateau and it is likely that these represent ancient communication lines, but as with central Taveuni, the generally rugged terrain and high rainfall make the area unattractive for settlement.

Within the past 30 years or so the region has been subject to a variety of human activities: initially forestry and then the construction of a dam for hydro-electricity. As a consequence a road now crosses the plateau from the south-east to north-west and access is readily available to many parts of the plateau.

5.2 Nadrau Swamp: the Local Environment

5.2.1 The Physical Setting

The Nadrau Swamp lies at about 760 m asl, on the edge of the divide between the Rewa and Sigatoka Rivers near the headwaters of Nanuku Creek. This is within the forest, near the *talasiga* boundary, Figure 5.4. Rodda (1976, 1984) mentions minor tectonic tilting on the plateau which has elsewhere blocked valleys and created temporary lakes and may explain the presence of Nadrau Swamp so close to the edge of the Sigatoka River catchment. The swamp is fed by several short streams and Nanuku Creek joins the valley from the south and flows around the downstream margin of the swamp. A small levee has built up along Nanuku Creek and it is possible that this was also sufficient to cause damming of the valley.

Organic sediments have accumulated within the valley and cover approximately 114 ha. The swamp surface was surveyed using an automatic level along several transects across the swamp and back along the northern margin to the datum. The contours shown in Figure 5.5 are relative to the lowest surveyed point on the swamp. There is a fall of approximately 8 m from west to east on the swamp, with some doming evident in the eastern section.

A comparison of the height of the levee and the heights of the swamp above datum suggest that the levee is a minor feature and may have initiated the accumulation of sediments in the valley, but the growth of peat above the levee was probably a biological process, i.e. that of a ground water fed swamp maintaining a water table above the local level.

Preliminary stratigraphic borings of the site revealed the deepest peat profiles lay beneath the domed area in the main part of the swamp and this area was chosen for intensive stratigraphic and palynological analysis.

5.2.2 The Local Vegetation

The vegetation immediately surrounding the swamp is forest, parts of which have been cleared of undergrowth to facilitate cattle grazing, or clear-felled for gardens. Berry and Howard (1973) note that dominant taxa in the remaining forest are *Endospermum macrophyllum*, *Parinari insularum*, *Agathis vitiensis*, *Dacrydium nidulum*, *Podocarpus neriifolius* *Palaquium* sp., *Dysoxylum richii*, *Calophyllum* spp. and species of Myrtaceae. However, at the very edge of the swamp the vegetation is much disturbed. On the eastern margin the vegetation consists of an almost monospecific stand of *Erythrina* sp. which was presumably deliberately planted. The western margin of the swamp has a low forest of

Figure 5-4: Nadrau Swamp and its Environs

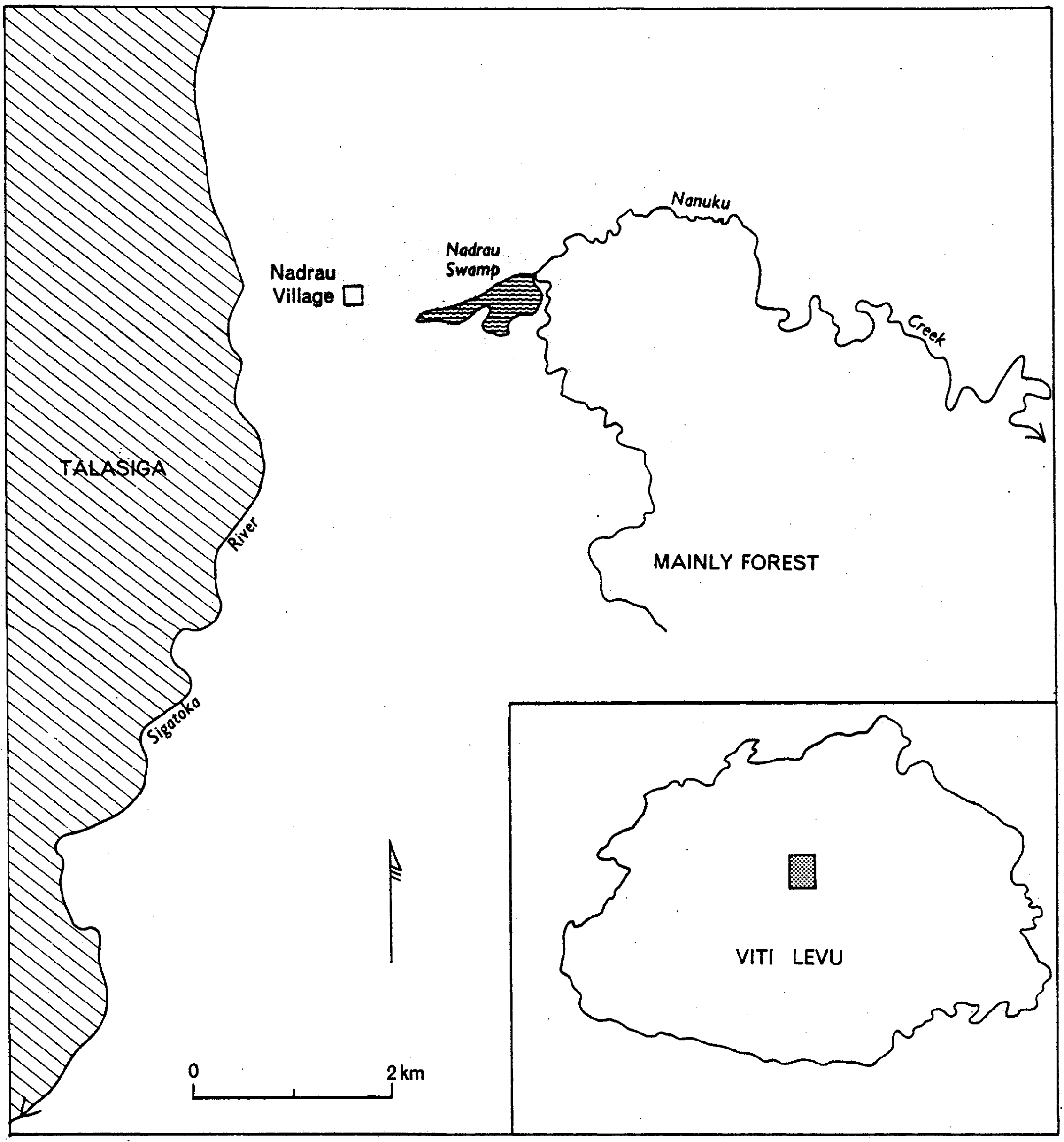
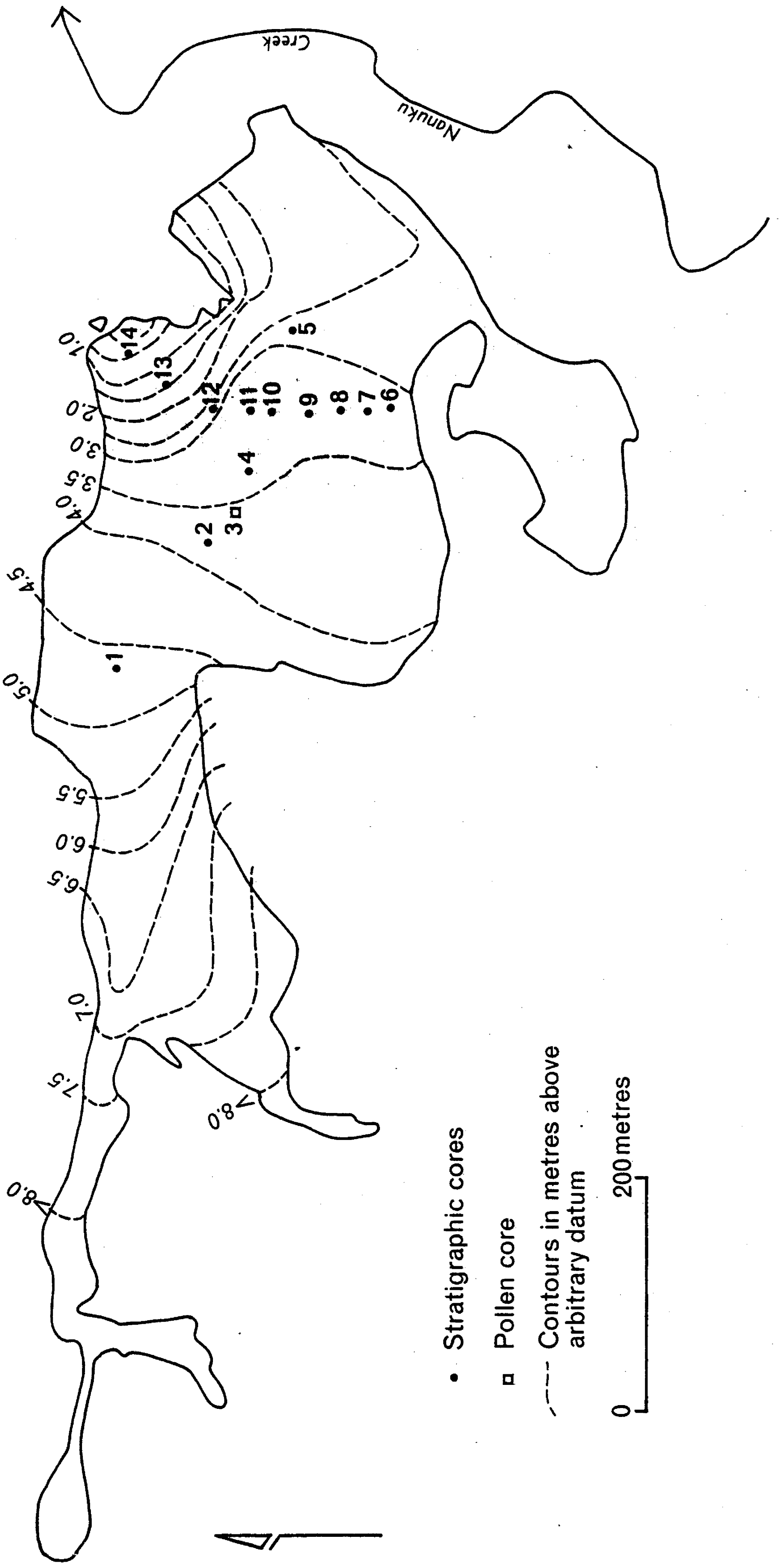


Figure 5-5: Nadrau Swamp: Core Sites and Levels



Decaspermum vitiense, *Aglaia elegans*, *Podocarpus neriifolius*, *Garcinia pseudoguttifera* and *Dacrycarpus imbricatus* with an understorey of *Psidium guajava*, *Lindernia diffusa*, *Ageratum houstonianum*, *Sphaerostephanos unitus* and *Phymatosorus scolopendria*.

The wetland vegetation at Nadrau Swamp has been severely disturbed by the cattle grazing and trampling on the swamp surface, although there are no apparent attempts at drainage of the swamp to improve grazing conditions. The swamp vegetation has been briefly described by Ash and Ash (1984) and they note that it is characterised by a high proportion (79%) of introduced taxa, a figure much higher than that for other wetland areas on Viti Levu.

All plant taxa observed at Nadrau Swamp were collected and identified either in the field or at the SUVA herbarium. The vegetation was distributed homogeneously at the site (see Figure 5.6) and abundance of taxa was estimated as either frequent or occasional. All taxa observed and their respective abundances are listed in Table 5.2. The only common native taxon is *Eleocharis dulcis*, but the introduced sedges, *Cyperus pilosus*, *Kyllinga brevifolia* and *Rhynchospora corymbosa*, and grass, *Paspalum conjugatum* are usually more abundant.

The trampling by cattle has resulted in the formation of sedge and grass hummocks up to 50 cm high, mainly near the edges of the swamp. The species composition in these areas does not differ from the main part of the swamp.

The pond at the south-western end of Nadrau Swamp is ephemeral but supports several aquatic taxa including *Limnanthemum indicum*, *Eleocharis dulcis*, and *Nymphaea capensis*.

5.3 Nadrau Swamp Stratigraphy

The stratigraphy of Nadrau Swamp was determined from two transects of stratigraphic cores, one longitudinal (Cores N1 to N5) and one across the swamp (Cores N6 to N14). Cores were extracted using a D-section corer and their locations are shown on Figure 5.5. The results are presented diagrammatically on Figure 5.7 and related to heights above and below the surveyed datum.

The majority of the cores display a similar profile with the following stratigraphic units.

1. There is a surface root mat of sedges extending up to 20 cm in depth.
2. The root mat passes into fresh sedge peat up to 4 m deep, which is highly organic with identifiable remains of sedge roots and shoots. Towards the base there are often large pieces of wood in the material.

Figure 5-6: Vegetation on Nadrau Swamp

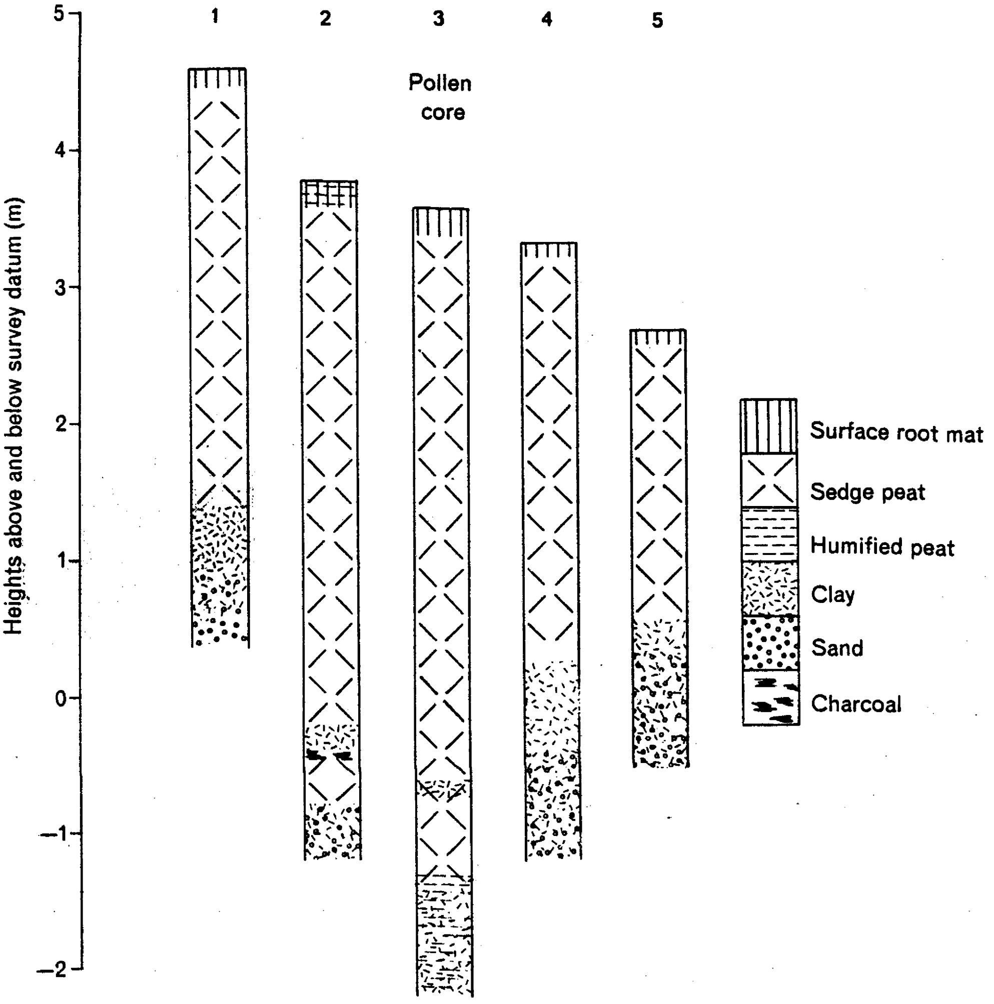
Table 5-2: Nadrau Swamp Vegetation

Species	Abundance
Pteridophytes	
Nephrolepis biserrata	+
Sphaerostephanos unitus	+
Angiosperms	
**Cyperus pilosus*	++
Eleocharis dulcis	++
**Kyllinga brevifolia*	++
**Rhynchospora corymbosa*	++
**Paspalum conjugatum*	++
x*P. orbiculare*	+
**Sacciolepis indica*	+
Commelina diffusa	+
x*Urena lobata*	+
Adenostema lavenia	+
**Cuphea carthaganensis*	++
**Desmodium heterophyllum*	+
**Mikania micrantha*	++
x*Polygonum dichotomum*	+
**Ludwigia octovalvis*	+

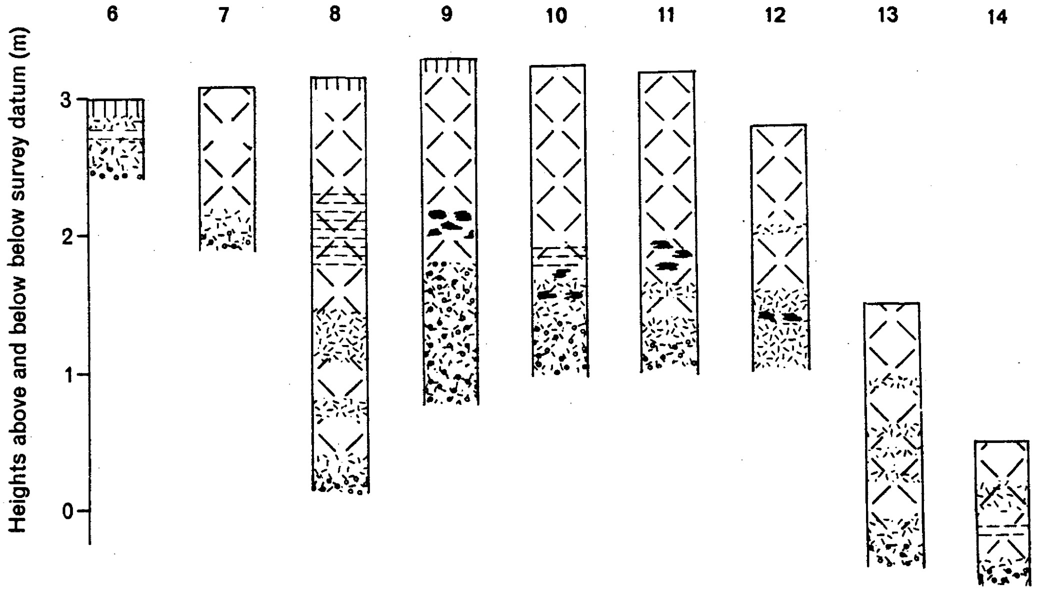
++ = frequent + = occasional
* = european introduction
x = probable aboriginal introduction

Figure 5-7: Stratigraphic Cross-Sections of Nadrau Swamp

Longitudinal Section



Cross Section



3. With increasing depth the sedge peat becomes more humified and less organic. There is a subtle transition to the underlying stratigraphic unit.
4. The basal sediments are generally inorganic, becoming more obviously banded and clayey with depth. At the base of the cored sediments the material is often sandy and impenetrable with the D-section corer.

Cores extracted from towards the margins of the swamp (Cores N6, 7, 8, 12, 13 and 14) vary slightly from the generalised profile in that they incorporate clay layers within the peat.

The stratigraphic profiles suggest the basin originally had water flowing slowly through it, depositing the clays and sand at the base. At a later stage water-flow may have slowed, or ceased and waterlogging may have occurred, allowing for development of peat forming communities at Nadrau Swamp. The valley may have become dammed at this time, perhaps by tectonic tilting or the build-up of the levee, allowing water to accumulate in the valley. Once established, this vegetation continued to build up a peat deposit and simultaneously raise the local water table within the peat. Swamp conditions then prevailed until the present.

The presence of clay layers in marginal cores suggests there has been periodic minor flooding from Nanuku Creek over the levee, which did not cover the entire swamp.

5.4 The Nadrau Swamp Pollen Diagrams

5.4.1 Methods

The pollen core (Core N3) was extracted with a D-section corer in 50 cm sections to a depth of 6 m, retained in PVC tubing, and sealed with plastic and tape for transport to the laboratory. Material for ^{14}C dating was collected from the base of the organic sediments.

Samples for pollen analysis, moisture and organic determinations were extracted from the core at 20 cm intervals and prepared in the manner described above for the surface and Lake Tagimaucia samples. Upon consideration of the results from the modern surface samples presented in Chapter 3 it was decided to adopt the dryland pollen taxa as the pollen sum, since changes in dryland vegetation were of interest at this site. Pollen counts continued until 200 grains of dryland pollen had been recorded; all swamp and pteridophyte taxa encountered during the count were also recorded, but calculated outside the pollen sum. Pollen concentrations were calculated on the basis of the 1 cm^3 sample used for the pollen analyses.

Fire has often been cited as an agent of deforestation in the islands of the south-west Pacific (Kirch 1983) and more specifically in Fiji by Hughes *et al.*

(1979). A count of carbonised particles in association with the pollen counts was therefore attempted using the point-count method of Clark (1982) in which the carbonised particle abundance is calculated as $mm^2\ cm^{-3}$. An error margin of 25% was adopted. The carbonised particle abundance curve is presented beside the dryland pollen curves on both the percentage and concentration diagrams.

5.4.2 ^{14}C Dating and Stratigraphy of the Pollen Core

Dating

A single radiocarbon date has been determined on this core: ANU-3810 from 472.5 to 482.5 cm, yielding the reported ^{14}C age of 2090+/-110 BP. This horizon marks the onset of organic deposition at the site and suggests a fairly rapid rate of accumulation (approximately 23 cm per 100 years). No attempt was made to calculate pollen influx rates in this core since it was felt that the deposition rates were not well enough established.

Stratigraphy

The stratigraphy of the pollen core is presented on the swamp pollen diagram, Figure 5.8 and described below.

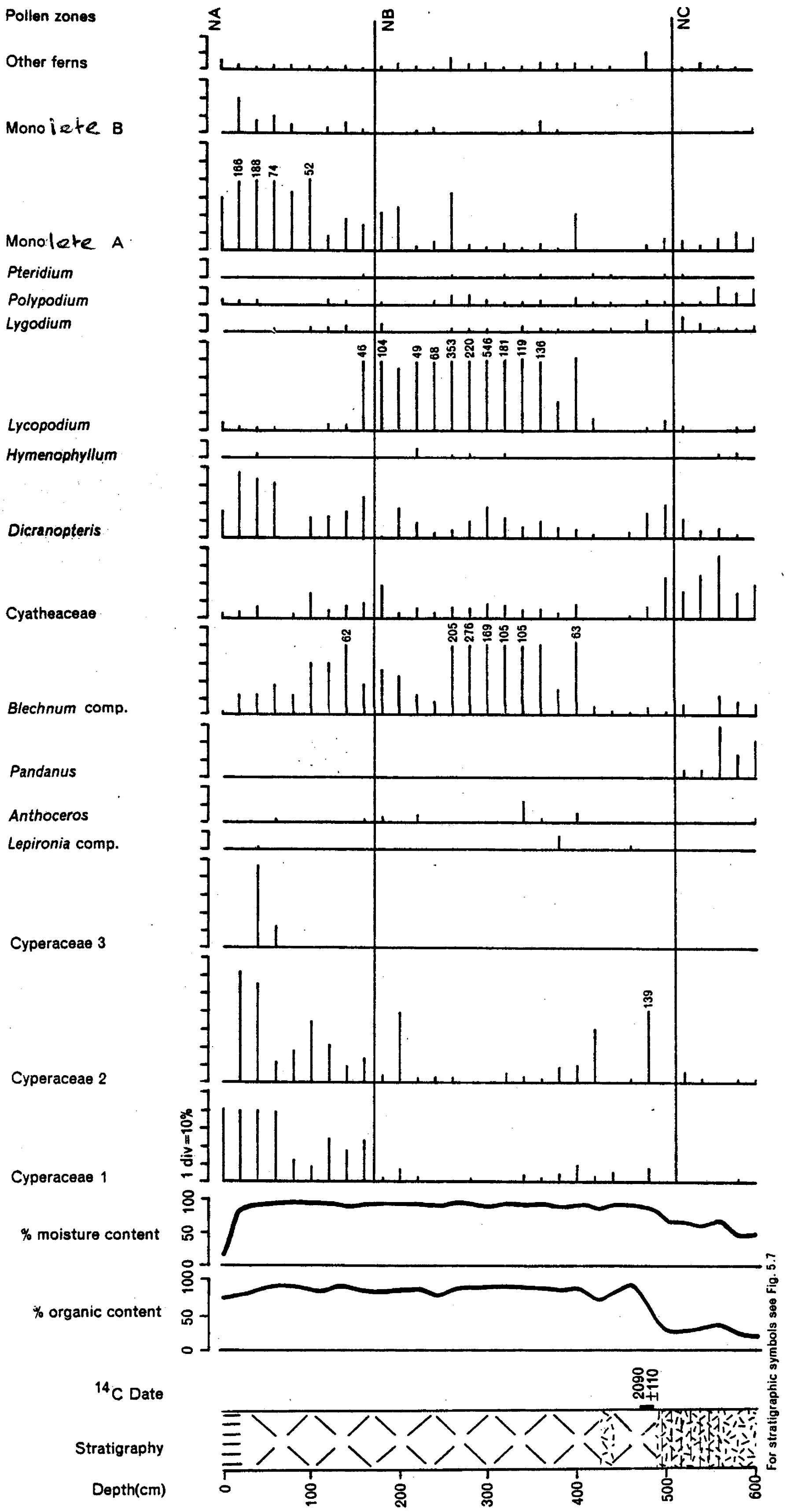
0 - 15 cm	Dry (12% moisture at surface), humified sedge root mat. Organic content is about 75%.
15 - 425 cm	Fresh brown sedge peat, including much root and shoot material. Moisture and organic content is high, averaging 90% and 80 to 90%, respectively.
425 - 432 cm	Yellow-grey clay horizon in which the organic content falls to 70%.
432 - 485 cm	Sedge peat as above. Both moisture and organic contents begin to decline in the lower horizons of this layer.
485 - 570 cm	Banded clay with some organic material. Moisture content is approximately 60% in this layer and organic content is about 25 to 30%.
570 - 600 cm	The basal sediments are stiff yellow/grey clays with low organic content (<20%).

5.4.3 The Swamp Pollen Diagrams

The swamp pollen percentage diagram

The percentage curves for swamp pollen taxa are presented on Figure 5.8 with the stratigraphy and sediment determinations. Percentages were calculated on the basis of the dryland pollen sum of 200 grains. The taxa are mostly Cyperaceae, however, *Pandanus* has also been included since its pollen apparently does not travel far, except by water, and it has been observed growing on the Nadrau Plateau in pure stands in swamp situations. Pteridophyte taxa have also been included on this diagram due to the high incidence of ferns in the present swamp vegetation. It was felt that they may have played a significant role in the wetland

Figure 5-8: Nadrau Swamp: Percentages of Swamp Taxa



vegetation in the past, especially in view of the likelihood of a depauperate pre-european swamp flora in Viti Levu.

The diagram has been subjectively divided into three zones (NA to NC) which are described below.

NC 600 - 520 cm	The basal zone is characterised by high, but declining values for *Pandanus*. This taxon virtually disappears from the record above this zone. The ferns are best represented by Cyatheaceae.
NB 500 - 180 cm	Zone NB has quite high although erratic representation by *Eleocharis* comp. and consistent representation by Cyperaceae 1. The liverwort, *Anthoceros* has quite high values in the middle of the zone. Extremely high representation is shown by *Blechnum* comp. and *Lycopodium*.
NA 160 - 0 cm	The uppermost zone has consistently high representation by Cyperaceae 1 and slightly lower, consistent values for *Eleocharis* comp. There are erratic, but high appearances by Cyperaceae 2 and 3. *Lycopodium* decreases quite markedly and there is a less dramatic reduction in *Blechnum* comp. *Dicranopteris* and Monolete A increase.

The swamp pollen concentration diagram

Swamp pollen concentrations calculated as grains cm^{-3} are presented on Figure 5.9. The values closely follow the changes on the percentage diagram. Concentrations are high from 600 to 520 cm, largely due to high values for *Pandanus* and Cyatheaceae. Concentrations are more erratic in the central part of the core, but high above 340 cm due to high concentrations of *Lycopodium* and *Blechnum* comp., and consistently high above 160 cm.

5.4.4 The Dryland Pollen Diagrams

The dryland pollen percentage diagram

Percentages of dryland pollen taxa and the abundance of carbonised particles are presented on Figure 5.10. The diagram has been divided into two zones (N1 and N2) on the basis of changes in the major dryland taxa. These changes are described below.

N2 600 - 520 cm	This zone is characterised by consistent representation for several forest taxa which are not repeated in any samples higher in the sequence. These taxa include *Dacrydium*, *Podocarpus*, Cunoniaceae, *Calophyllum*, Myrtaceae, and *Pterandra*. The reduction in representation or disappearance of these taxa marks the top of this zone. Carbonised particles are generally low.
N1 500 - 0 cm	There is increased representation by several taxa throughout this zone, most significantly by Poaceae, but to a lesser degree by *Bischofia*, *Omalanthus*, Urticaceae 1 and 2, *Parasponia/Celtis* and Asteraceae. There are further increases in Asteraceae towards the surface. Carbonised particles are more common near the base of

Figure 5-9: Nadrau Swamp: Concentrations of Swamp Taxa

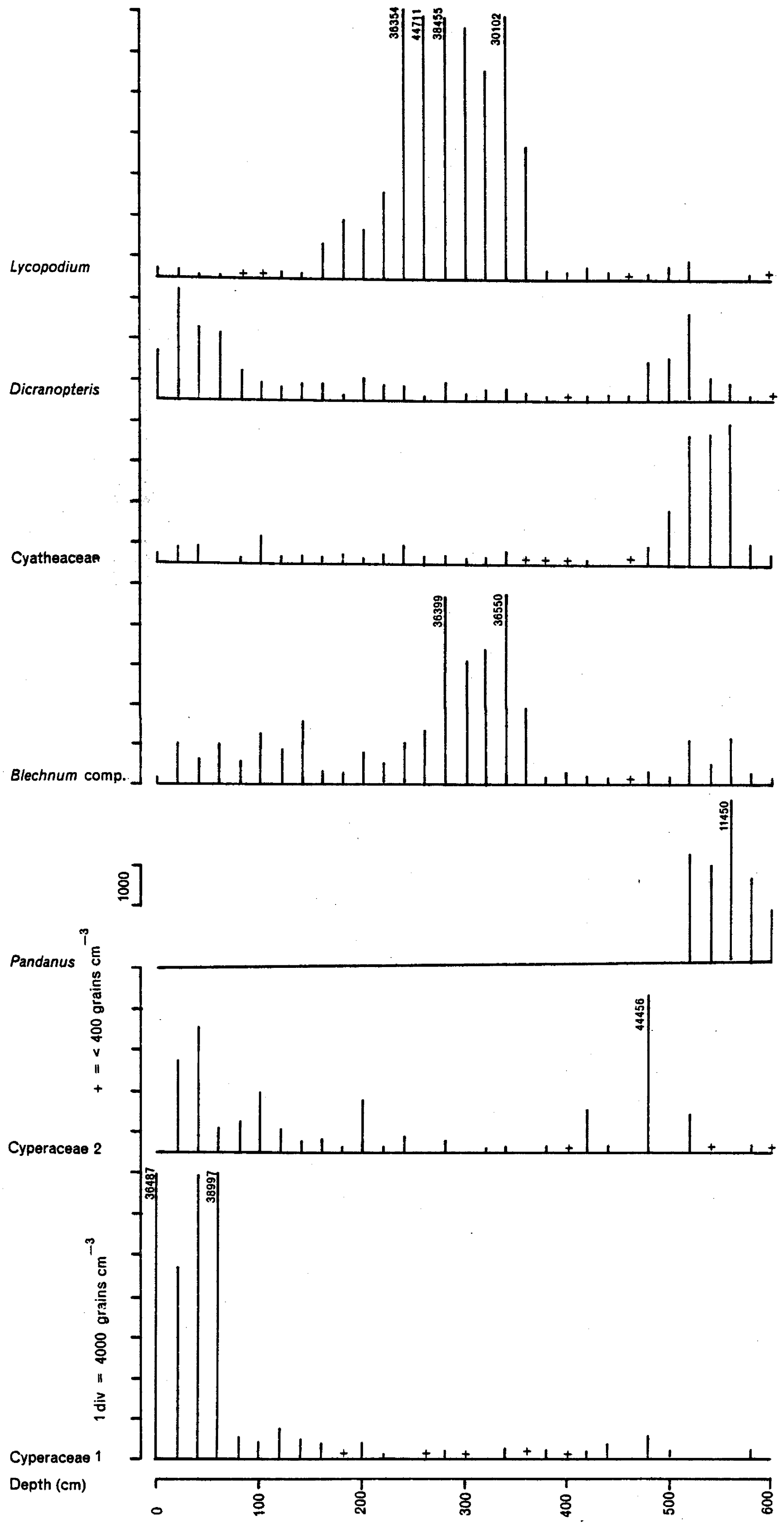
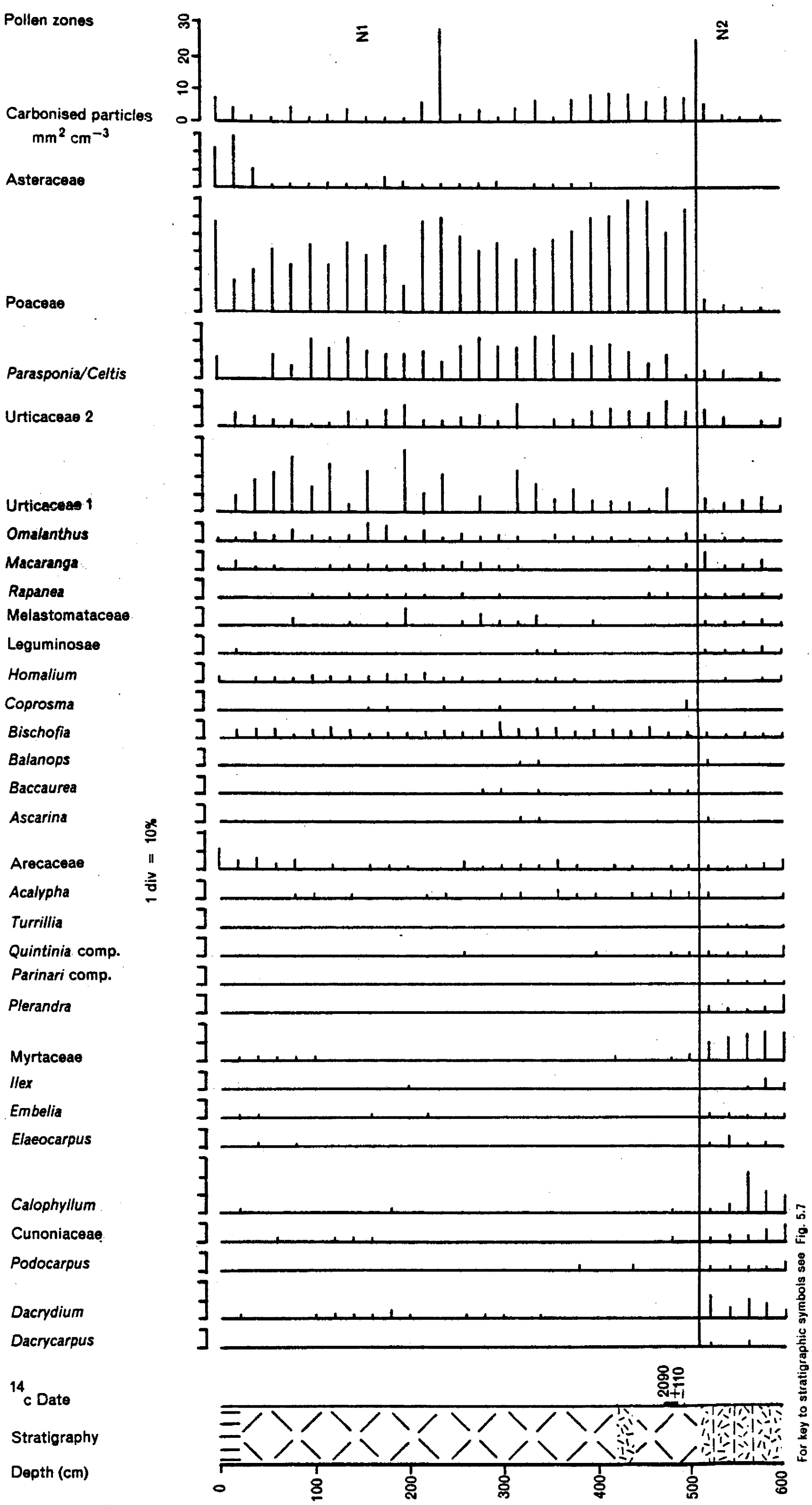


Figure 5-10: Nadrau Swamp: Percentages of Dryland Taxa



this zone and decline towards the surface, except for a single very high value at 240 cm.

The dryland pollen concentration diagram

The pollen concentrations of dryland pollen taxa presented on Figure 5.11 closely follow the pattern of the percentage diagram. Fairly high concentrations of forest taxa are displayed below 520 cm, although some show continued high concentrations above this, for example *Quintinia* comp., Myrtaceae and *Rapanea*. Concentrations of Poaceae begin to increase from about 540 cm. There is a noticable correlation between the very high carbonised particle value at 240 cm and high concentrations of Poaceae and Urticaceae 1 at the same level. Asteraceae shows the most significant increase in the upper samples.

5.5 Discussion

5.5.1 Development of Nadrau Swamp

A tentative interpretation of the development of the swamp was presented above, based upon the stratigraphic profiles. It is possible to compare this proposed development with the sequence of swamp vegetation changes displayed in the pollen diagrams.

The swamp pollen assemblages suggest that the basal sediments probably accumulated slowly under a *Pandanus* swamp. *Pandanus* also occurs in the forests, however modern pollen samples suggest that its pollen rarely travels far except by water and it seems most likely that the *Pandanus* pollen was derived from *in situ* vegetation. There are modern analogues for this community in many wide valleys with gentle gradients elsewhere on the plateau. The vegetation is dominated by *Pandanus*, with occasional sedges as an understorey, see Figure 5.12. There is often standing water in the valleys, but slow throughflow is usually maintained.

At about 2090 BP the sediments change from fine clays to peat and the swamp pollen spectra show a decline in *Pandanus* and increases in the cyperaceous taxa, *Eleocharis* comp. and Cyperaceae 1. The *Pandanus* community was apparently replaced by a sedge swamp at this time. The vegetation change may reflect a change in drainage through the valley from a situation where gentle throughflow persisted to a situation where drainage was impeded. Such a change would favour the establishment of a peat producing sedge community at Nadrau Swamp. The reasons for this change might include an abrupt increase in sediment transport in the area which created the levee on Nanuku Creek, to the south-east of the present swamp, and impeded drainage in the Nadrau Swamp valley, or some

Figure 5-11: Nadrau Swamp: Concentrations of Dryland Taxa

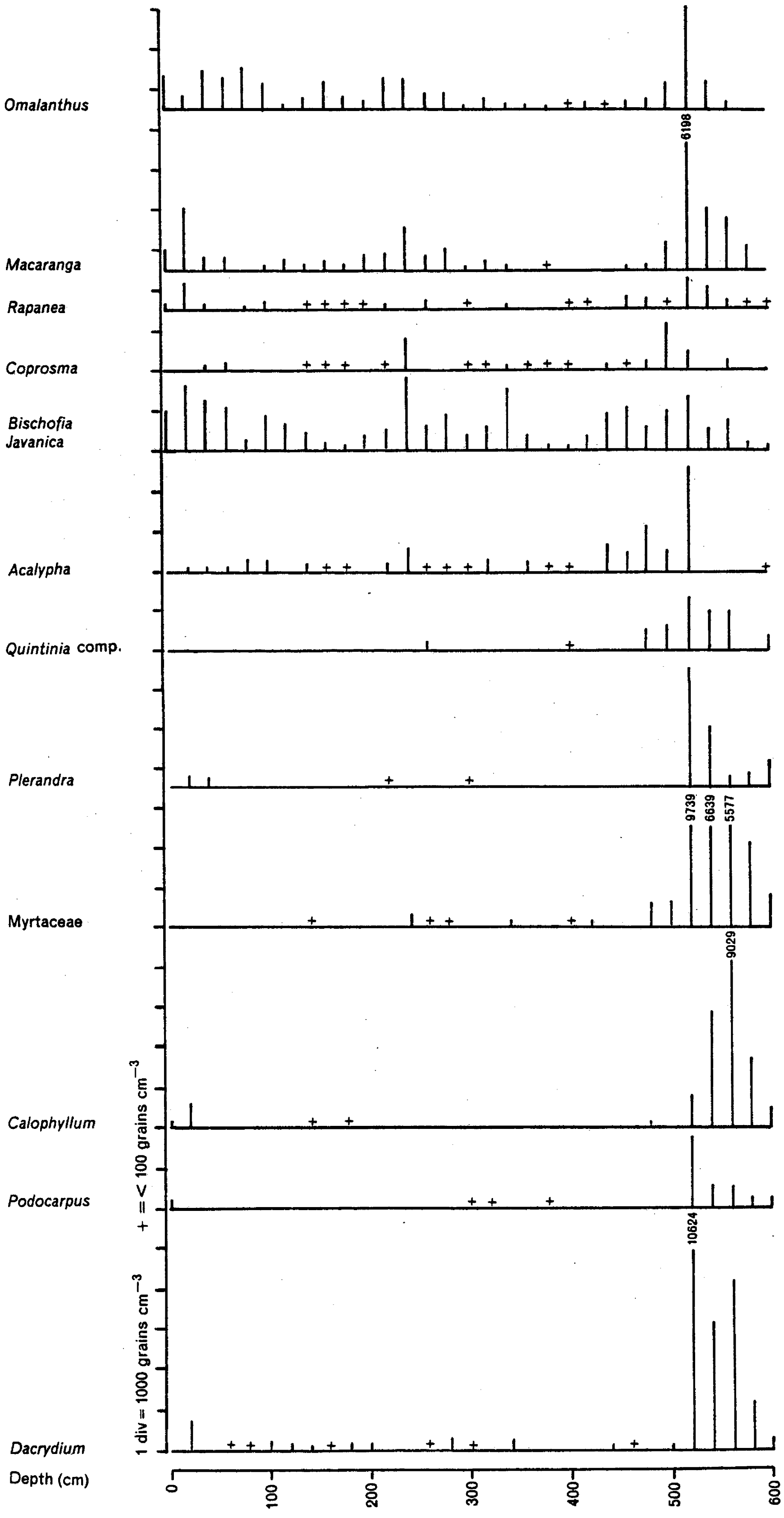


Figure 5-11 cont'd

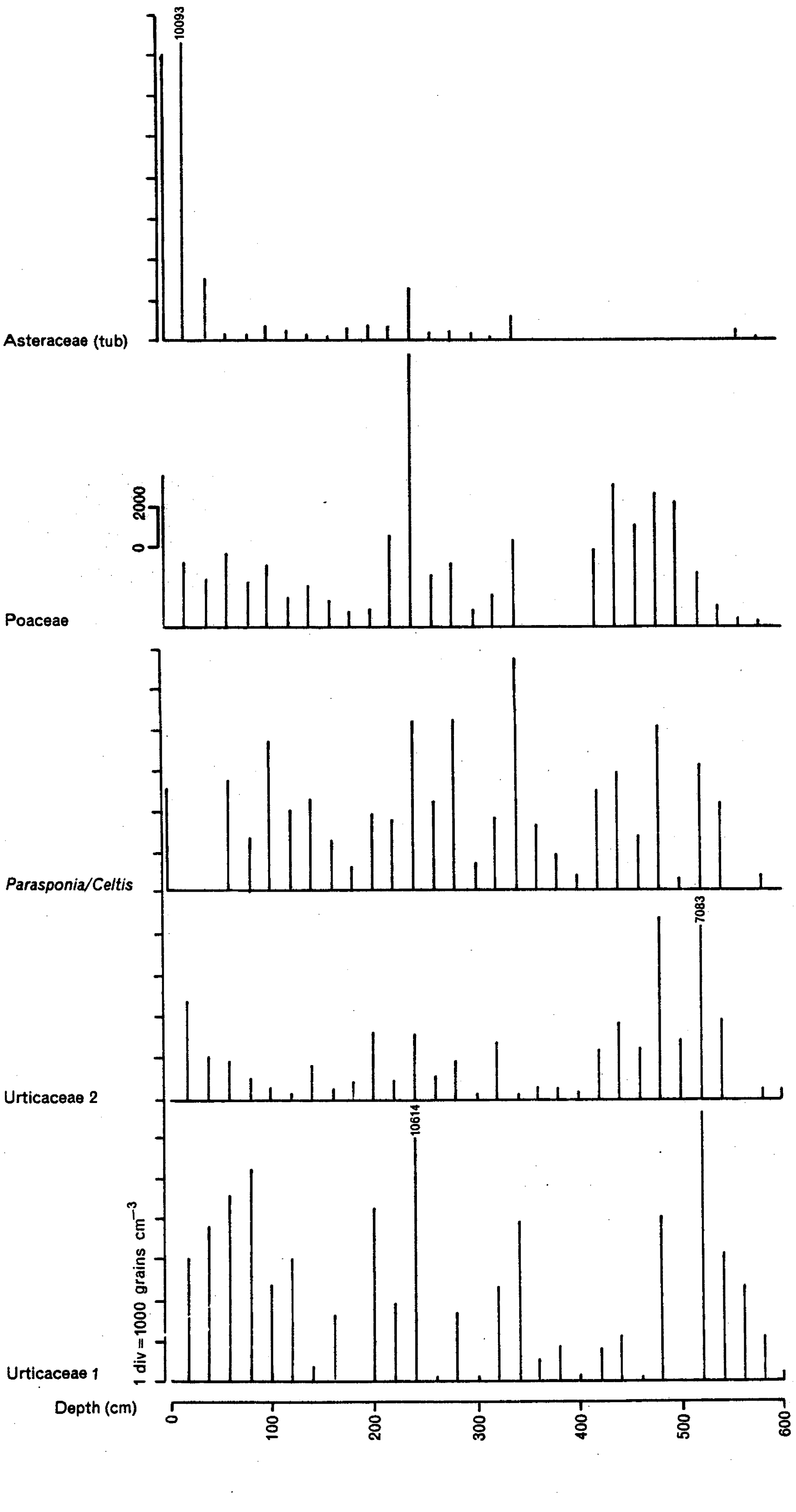


Figure 5-12: *Pandanus* Swamp on the Nadrau Plateau

minor tectonic tilting interrupted drainage in the area. The change may be the result of a combination of these factors. Alternatively, blockage of the valley may have occurred earlier and the change from *Pandanus* to a sedge community occurred as waterlogging increased.

While the swamp vegetation probably had abundant sedges, it is likely that ferns were also important components of the wetland vegetation. Very high values for pteridophyte taxa occur in zone NB, especially *Blechnum* comp. and *Lycopodium*, although the latter may well have been occurring in the dryland vegetation also. Peat deposition is interrupted by a layer of clay from 425 to 432 cm which may indicate extensive flooding of Nanuku Creek. Clay horizons appear frequently in stratigraphic cores extracted close to the margins of Nadrau Swamp which suggests that periodic minor flooding has occurred in the past.

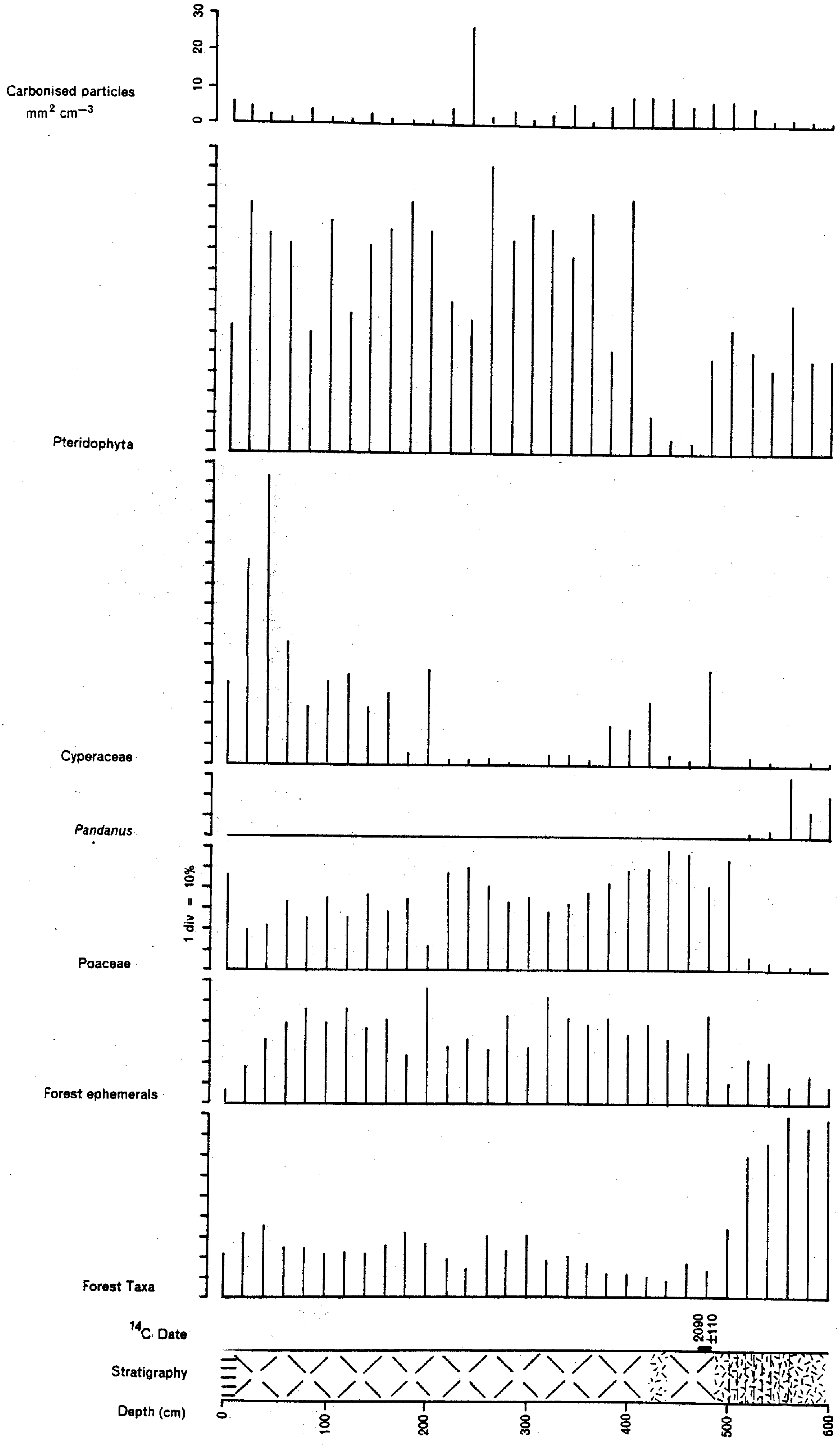
At the zone NB/NA boundary there is a dramatic increase in the percentage representation and concentrations of Cyperaceae 1 and *Eleocharis* comp., suggesting they became more firmly established at the site at this time. Extrapolation of sedimentation rates from the ^{14}C date of 2090 BP at 472.5 to 482.5 cm suggests these changes occurred at about 700 BP. *Lycopodium* is uncommon above this horizon, while Monolete A and *Dicranopteris* assume greater importance. It seems likely that during the past 700 years or so the swamp has supported vegetation similar in structure to the present, although probably with less diversity since certain presently common taxa (e.g. *Cyperus pilosus*, *Kyllinga brevifolia*, *Rhynchospora corymbosa*, and *Paspalum conjugatum*) have been introduced only during the very recent past.

5.5.2 Changes in the Dryland Vegetation

In the early part of the sequence there is a marked coincidence of changes in stratigraphy, swamp pollen spectra and dryland pollen spectra, see Figure 5.13. During the early phase of deposition at Nadrau, before 2090 BP, while a *Pandanus* swamp probably occupied the valley, the dryland forest pollen spectra are diverse and show their most significant representation for the entire sequence.

Gymnosperm taxa are important at this time, especially *Dacrydium*, and since its pollen is not well dispersed, it may have been growing quite close to the deposition site. Abundant *Calophyllum* and species of Myrtaceae are also indicated as components of the vegetation. A comparison with the modern pollen spectra from central Viti Levu discussed above (Chapter 3) suggests the surrounding forest closely resembled the tropical evergreen ombrophilous montane forest described by Berry and Howard (1973) for the less disturbed parts of the Nadrau Plateau.

Figure 5-13: Summary Pollen Diagram from Nadrau Swamp



For key to stratigraphic symbols see Fig. 5.7

The virtual disappearance of these forest taxa after about 2090 BP and their apparent replacement by Poaceae, *Bischofia*, *Omalanthus*, Urticaceae, and *Parasponia/Celtis* indicates a dramatic change in the dryland vegetation. The very high percentage representation and concentration of Poaceae after 2090 BP suggests that grassland vegetation probably dominated the catchment and nearby following deforestation. Notably, those taxa which assume importance with Poaceae are presently associated with areas of forest disturbance (Berry and Howard 1973) and rarely dominate in closed forest situations.

It is tempting to associate the likely catchment deforestation with the simultaneous changes in swamp stratigraphy and vegetation. It is possible that the removal of nearby trees increased sediment run-off from the slopes and thereby supplied material for the formation of the levee and created conditions which ultimately favoured the establishment of a peat swamp.

The apparent reduction in forest cover near Nadrau Swamp is difficult to explain in terms of climatic change. Although much drier conditions would have been able to effect the changes, it is unlikely that climatic conditions have varied significantly in the past 2000 years and present rainfall at the site (about 2663 mm per annum), despite being seasonal in distribution, is sufficient to support closed forest such as that which the pollen spectra suggest existed before 2090 BP.

The increased abundance of carbonised particles at about the same time as the reduction in forest elements suggests that fire may have played a part in the changes. In most south-west Pacific island contexts, fire is regarded as a tool used to facilitate clearing for the shifting cultivation practised by early inhabitants. This situation also applies in Fiji. The earliest dates for occupation of coastal Fiji cluster around 3000 BP and it seems reasonable to suggest that using slash and burn techniques of clearance it would have taken the early occupants at least 1000 years to move as far inland as the Nadrau Plateau. The steep gradients which surround the plateau may have slowed movement towards Nadrau and onto the plateau, and probably formed a natural barrier to further expansion. Very steep rainfall gradients towards the east may have restricted the application of slash and burn agriculture further onto the plateau region. Certainly there is no evidence of early forest clearance on the central part of the Nadrau Plateau, and the forest/*talasiga* boundary closely follows the edge of the plateau.

Alternatively, minor tectonic tilting in the area, as was suggested by Rodda (1976, 1984), could have initiated the same sequence of deforestation, levee formation and impeded drainage in the valley, although increased carbonised particles would not be anticipated. But it might be expected that under such circumstances the vegetation would have recovered during the past 2000 years and regained its former complexity and species composition. This does not appear to have occurred at Nadrau and the former explanation of human disturbance is preferred.

The presence of woody taxa in the pollen spectra throughout zone N1 suggests that the vegetation was probably a mosaic of grassland and pockets of forest to the west of Nadrau Swamp, with forest to the east, similar to the situation which prevails at present. Conditions appear to have remained relatively stable during this period, until the very recent past when Asteraceae became common for the first time. The plants represented by this pollen taxon are probably european introductions which have recently expanded in range.

Carbonised particle concentrations are generally lower in the top half of the sequence, except for an isolated high value at 240 cm. Clark (1983) discusses the transport and preservation of carbonised particles in organic deposits and suggests particularly high values may represent either fires within the catchment after which conditions were ideal for the preservation of the carbonised material in the sediments (for example, heavy rain immediately following fire), or a peak may represent a fire on the swamp itself. The carbonised particle peak at 240 cm is associated with an increase in concentrations of Poaceae and Urticaceae 1 which therefore may indicate temporary shifts in the vegetation composition due to a local fire.

The generally lower carbonised particle values may indicate fires became less frequent in the catchment toward the present. It is likely that destruction of the vegetation cover created conditions of reduced soil fertility and much increased soil erosion so that more open vegetation would have been self-sustaining and fire as a tool was not needed for keeping vegetation under control. The reduction in carbonised particles above 220 cm coincides with slight increases in the representation of forest taxa and secondary forest taxa at the expense of Poaceae. The landscape deterioration may have diminished the viability of the area for shifting agriculture and the population may have reduced, allowing the partial recovery of woody vegetation, at least in the sheltered gullies of the *talasiga*. There is evidence for abandoned villages and gardens along the forest/*talasiga* boundary (Berry and Howard 1973) to suggest that the population in the area was greater in the past. There are no dates for the establishment or abandonment of these villages, but the pollen record gives some clues. Using the estimated deposition rate at Nadrau given above, the changes which indicate a reduction in the local population occurred from about 1000 BP, although this estimate might be too early since compaction of the lower sediments is likely to have occurred. Material has been submitted for ^{14}C dating to confim this estimate, although the result is not yet available.

The very high values for Asteraceae towards the surface are probably indicative of the arrival of weed taxa in the area introduced since european contact.

5.6 Wainisavulevu Creek: The Local Environment

5.6.1 The Physical Setting

A 7 m sedimentary sequence consisting of laminated clays and organic horizons underlying a thick deposit of colluvium was exposed beside Wainisavulevu Creek during construction of a diversion weir for the Monasavu hydro-electricity scheme. The creek drains a large part of the Nadrau Plateau, see Figure 5.1, meandering across gentle gradients at about 900 m asl, before it leaves the plateau as a waterfall over the monzonite sill. Organic deposits are apparently uncommon in this part of the Nadrau Plateau, although this is probably due more to a lack of exploration in this inaccessible part of the island than to the absence of swamps. However, it was felt that a vegetation history from a less disturbed area would be useful to compare with the sequence from the obviously disturbed Nadrau Swamp area and the fortuitous exposure at Wainisavulevu Creek provided an appropriate site.

General rainfall patterns on the plateau suggest that Wainisavulevu Creek receives higher rainfall than Nadrau Swamp, and conditions are most likely to resemble those recorded at Monasavu. Hassall (1980) estimated the annual rainfall to be about 5000 mm, evenly distributed throughout the year near the site, which is a slightly higher figure than Monasavu. Average temperatures near Wainisavulevu Creek are probably similar to Monasavu.

Until construction of the weir and associated access roads, Wainisavulevu Creek flowed through one of the least disturbed parts of Viti Levu. There is no evidence of previous occupation of the area, although several foot tracks cross the plateau and prove that people passed through, at least occasionally, perhaps for hunting or escaping from hostile tribes elsewhere.

5.6.2 The Local Vegetation

The vegetation near Wainisavulevu Creek has been described by Hassall (1980) as tropical ombrophilous cloud forest, reflecting the very wet conditions on this part of the plateau. This forest type is characterised by its closed nature, canopy to 20 m, with many gaps and liane thickets, abundant climbing plants, epiphytic and terrestrial mosses and ferns. Common canopy taxa near Wainisavulevu Creek include *Calophyllum vitiense*, but the dominant species is the treefern, *Cyathea lunulata*. Other species recorded by Hassall include *Citronella vitiensis*, *Psychotria gibbsiae*, *Plerandra insolita*, *Metrosideros collina* and *Phaleria glabra*. Abundant climbers amongst the trees of the canopy include *Freycinetia impavida*, *F. caudata*, *Epipremnum pinnatum* and the fern *Lomogramma cordipinna*.

Acalypha rivularis and *Parasponia andersonii* are common along the banks of Wainisavulevu Creek, also the introduced taxa, *Mikania micrantha*, *Piper aduncum* and *Clidemia hirta*. The most common streambank ferns are *Blechnum orientale*, *Cyathea alta* and *Davallia fejeensis*.

In contrast to Nadrau Swamp, the surrounding vegetation shows little sign of disturbance and the few introduced species are restricted to tracks and creek banks (Hassall 1980).

5.7 Stratigraphy and ^{14}C Dating at Wainisavulevu Creek

Basement rocks in the excavated area are Pliocene conglomerates and sandstones and these underly the sediments in the Wainisavulevu Valley. The stratigraphy of the deposit is shown on Figure 5.14 and described below.

0 - 380 cm	Reddish brown colluvium.
380 - 385 cm	A very hard iron stained layer with corrugated surface.
385 - 535 cm	Lake clay deposits, orange-brown in the upper horizons and grey in the lower horizons.
535 - 660 cm	Laminated grey clay with organic layers.
660 - 750 cm	Alluvial sand and gravel.

Samples for pollen analysis were extracted from 500 to 650 cm.

A single date of 23 370+/-370 BP (ANU-4103) has been reported from wood located *in situ* at 506 to 520 cm, at the base of the lake clays.

It seems likely that the deposit resulted from partial damming of the valley and subsequent formation of a small lake. This may be related to the tectonic movements mentioned by Rodda (1976, 1984). The organic sediments, which contain abundant macrofossils (mostly leaves and stems) appear to have been deposited rapidly and it is likely the lake was ephemeral either because deposition quickly infilled the new basin, or further tectonic movements again altered drainage in the area.

Figure 5-14: Wainisavulevu Creek: Percentage Pollen Diagram

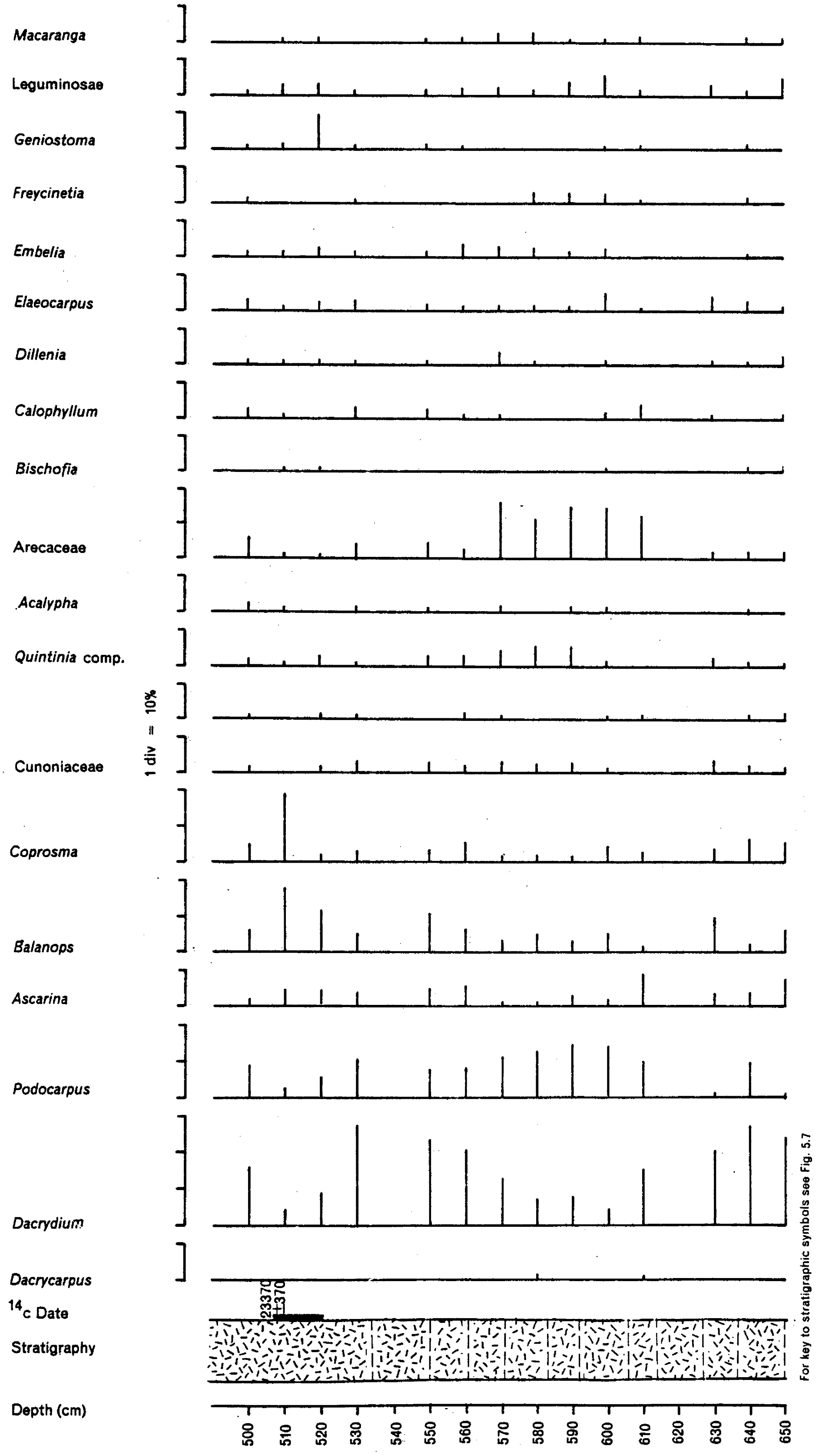
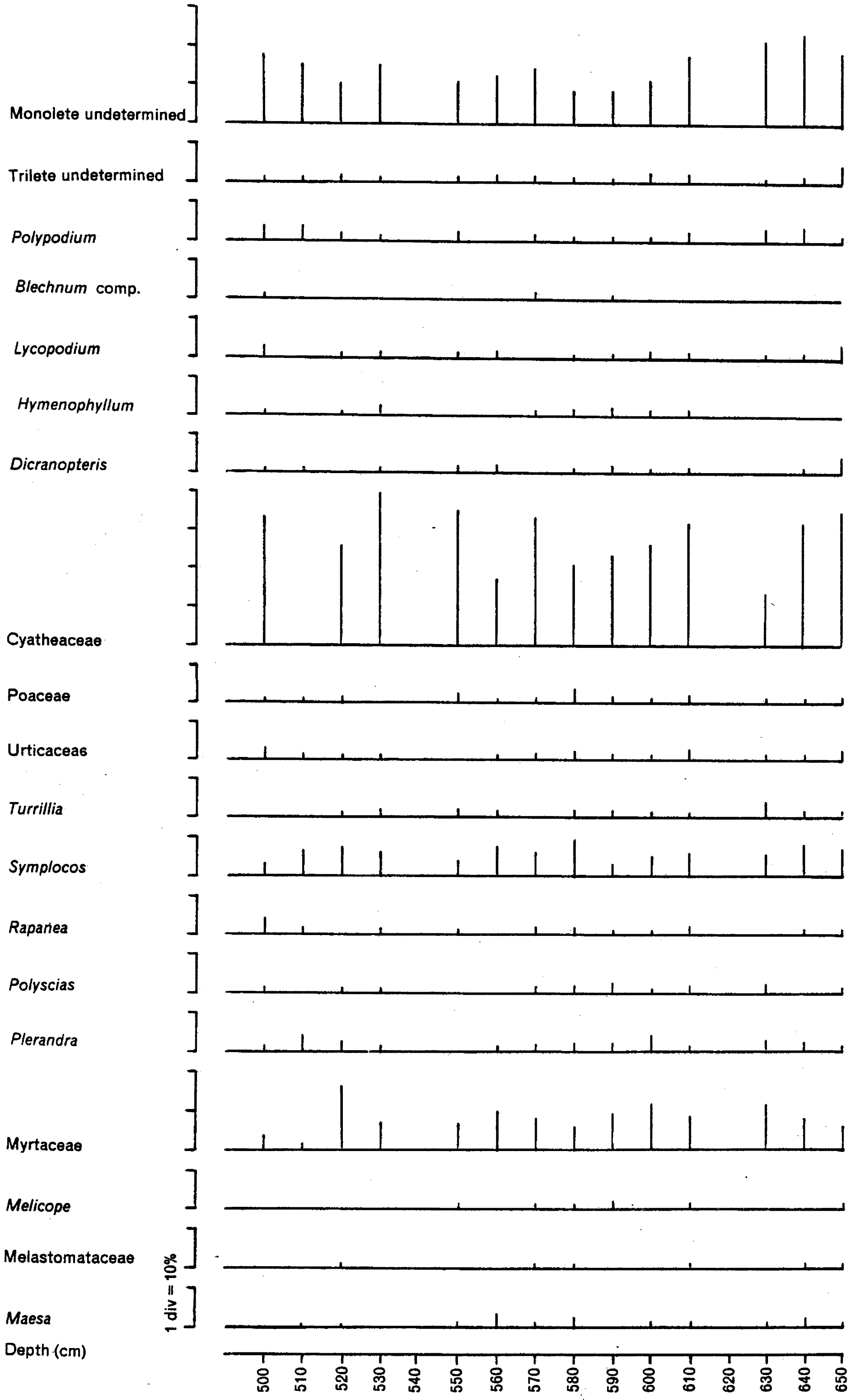


Figure 5-14 cont'd



The date of 23 370 BP from 506 to 520 cm provides a minimum age for the onset of accumulation, however, if fairly rapid deposition occurred, the origin of the site may not have preceeded this date by a significant amount.

5.8 The Wainisavulevu Creek Pollen Diagrams

Material for dating and pollen analysis was collected from a cleaned face of the exposure. Samples of 10 cm vertical depth were placed in separate plastic bags, labelled and sealed for transport to the laboratory. Samples for pollen analysis were processed and counted to 200 grains using the standard methods described above. Samples at 540 and 620 cm contained insufficient pollen to achieve a meaningful pollen count. Since the nature of the deposit suggested an ephemeral lake situation, it was assumed that there was no significant swamp vegetation and that the pollen sum should contain all pollen taxa. Ferns were again excluded because of their often high and erratic representation and the likelihood that their numbers are enhanced by preferential water transport, especially since they are noted as an important component of the riparian vegetation at present (Hassall 1980).

5.8.1 The Percentage Pollen Diagram

The percentage values for common pollen taxa from Wainisavulevu Creek are presented on Figure 5.14. Variation of pollen spectra in this short pollen sequence did not suggest any division of the diagram into pollen zones. Since it is likely that the sequence was deposited quickly, these spectra represent a glimpse of vegetation characteristics over a very short period.

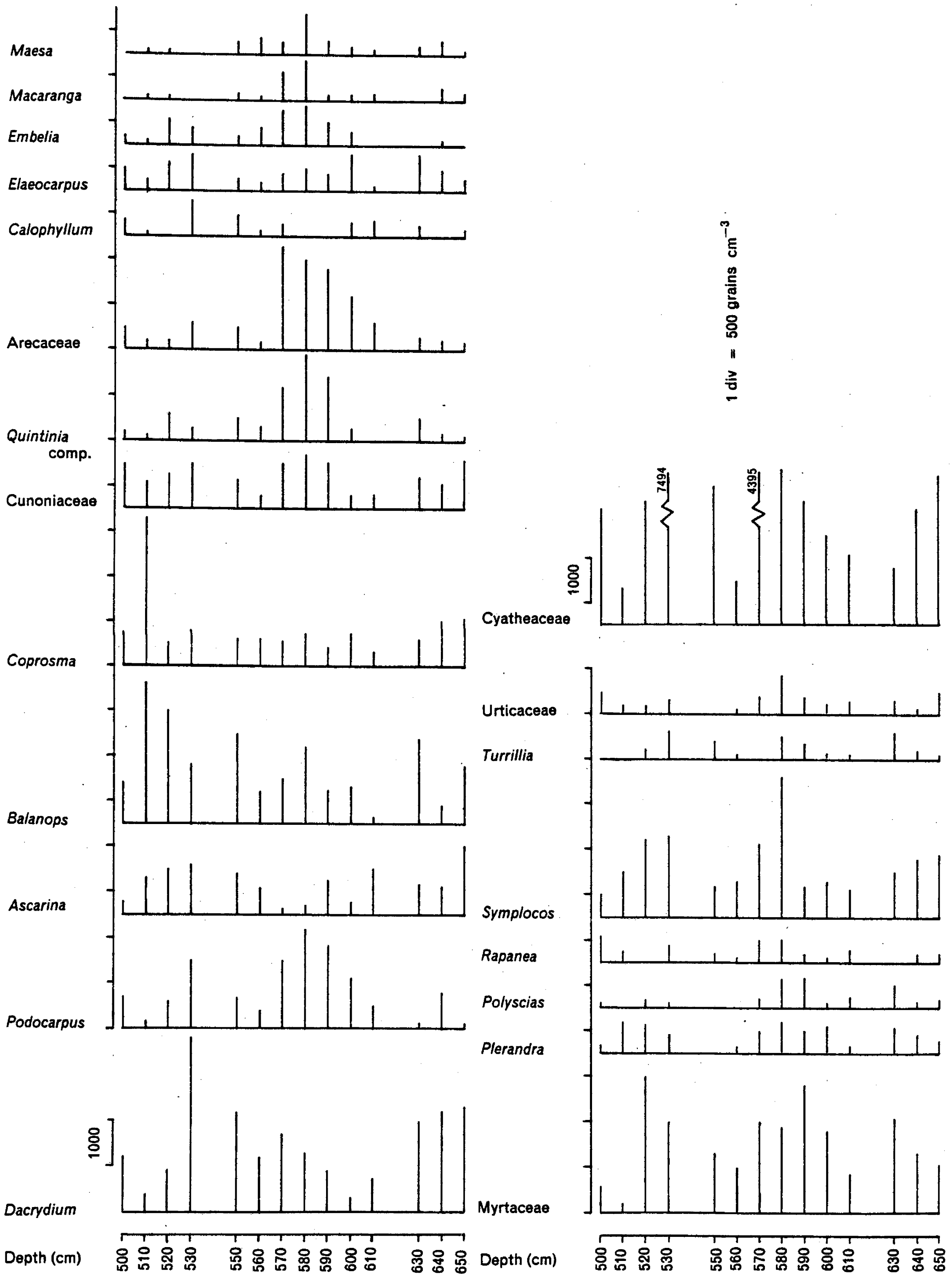
The most common forest taxa throughout the sequence are the gymnosperms, *Dacrydium* and *Podocarpus*. Moderately high values are also evident for Arecaceae, *Ascarina*, *Balanops*, *Coprosma*, Myrtaceae and *Quintinia*. comp. Poaceae, *Macaranga*, *Rapanea*, and Urticaceae have generally low representation. There are very high values for Cyatheaceae, moderately high values for *Blechnum* comp., and much lower representation by other pteridophyte taxa.

5.8.2 The Pollen Concentration Diagram

Pollen concentrations for the Wainisavulevu Creek pollen taxa are presented on Figure 5.15. The total concentrations for dryland taxa vary insignificantly. Total pteridophyte taxa show two large peaks, due to the vastly increased concentrations of Cyatheaceae.

The concentrations are generally lower than those recorded for Nadrau Swamp, but this would be expected if, as suspected, the Wainisavulevu Creek deposit accumulated very rapidly.

Figure 5-15: Wainisavulevu Creek: Concentrations of Selected Taxa



5.9 Discussion

The stratigraphy of the Wainisavulevu Creek sequence is suggestive of fairly rapid deposition, consistent with the formation of the site after minor tectonic tilting in the area. The pollen spectra thus probably represent a glimpse of the plateau vegetation at about 23 000 BP. Palynological, geomorphological and deep sea core information concur on the likelihood that at this time the south-west Pacific region was experiencing cooler and drier conditions as the height of the last glaciation was approached.

The plateau vegetation was apparently dominated by the gymnosperm taxa, *Dacrydium* and *Podocarpus*. Their percentage representation is much greater than values recorded in modern surface samples from the Nadrau Plateau area (see above, Chapter 3); even from forests which presently have relatively high proportions of gymnosperms.

The dominance of gymnosperm taxa parallels the basal pollen assemblages from Lake Tagimaucia. The values for *Ascarina*, *Balanops*, *Quintinia* comp. and *Coprosma* are also similar to the zone T5 Tagimaucia spectra and there may be parallels in the vegetation and environments of both sites. Several taxa which are indicative of cool, cloudy conditions at the present are represented in the Wainisavulevu pollen spectra, for example *Ascarina*, *Coprosma*, Cunoniaceae and *Quintinia* comp. This suggests that conditions near Wainisavulevu may have been characterised by persistent cloud cover, even though a seasonal rainfall regime is also implied. Cooler conditions than presently prevail are also indicated by the presence of these taxa, as would be expected if the cloud cover was increased. For these conditions to have affected the Wainisavulevu area, the cloud base over Viti Levu must have been much lower.

5.10 The Nature of Environmental Change on the Nadrau Plateau

The two pollen sites examined on the Nadrau Plateau have revealed entirely different aspects of its vegetation history. Unfortunately, the records are not contemporaneous and are necessarily considered separately in this section.

5.10.1 Wainisavulevu Creek

The Wainisavulevu Creek pollen diagram reveals a glimpse of the vegetation at about 23 000 BP on the Nadrau Plateau. A forest dominated by the gymnosperms *Dacrydium* and *Podocarpus* with the angiosperm taxa *Ascarina*, *Cosprosma*, *Quintinia* comp. and *Balanops* is suggested by the pollen spectra. This represents a considerable deviation from the present vegetation and is probably indicative of cooler and drier, or more seasonally drier, conditions than prevail at present. The pollen spectra in the sediments may not represent full glacial conditions on the plateau, and they bear a strong resemblance to the immediately post-glacial pollen spectra of the Lake Tagimaucia sediments from about 13 000 to 9000 BP. Remarkably similar forests may have occurred throughout windward Fiji before, during and immediately after the last glaciation.

5.10.2 Nadrau Swamp

The record from Nadrau Swamp covers the past 2000 years or so and contains a record of vegetation change which is unlikely to have been affected by climatic change. It seems more probable that the recorded fluctuations in the dryland vegetation are representative of anthropogenic disturbance.

Prior to 2000 BP the dryland vegetation consisted of a mixed community of rainforest taxa probably indicative of undisturbed conditions. The swamp vegetation was probably dominated by a *Pandanus* community. At about 2000 BP there were simultaneous changes from *Pandanus* swamp to Cyperaceae swamp; from inorganic to organic sedimentation; and from mixed rainforest to grassland with secondary forest taxa. These changes are probably related. It is possible that deforestation in the Nadrau Swamp catchment caused an increase in runoff and slope erosion, which blocked the valley, impeded drainage, and allowed the invasion of peat-forming taxa. The increased abundance of carbonised particles at the same time indicates fire may have caused the deforestation and this was probably related to human activity.

Subsequent developments in the dryland vegetation suggest a decrease in anthropogenic burning and the partial recovery of some forest taxa, but it is likely that soil degradation and erosion had occurred to such an extent that full recovery of forest vegetation was not possible. The reduction in burning may be related to this soil degradation. Fires may have been no longer required to reduce the woody vegetation, or perhaps because of reduced soil fertility, the area was no longer able to sustain a human population and there was an outward migration of people. These events probably occurred around 1000 BP.

The Nadrau Swamp pollen data indicate that forest communities existed at least at the margins of the present *talasiga* lands prior to the arrival of man. Since this site is at the contemporary forest/*talasiga* boundary it represents more favourable environmental conditions. Areas further west may have supported much more open wooded communities than Nadrau. The data do, however, show that the expansion of *talasiga* was dramatic under the influence of anthropogenic disturbance.

CHAPTER 6

THE POLLEN SITES: DELTA REGIONS OF VITI LEVU

The most obvious evidence of human impact on the Fijian environment comes from the leeward zones of the main islands, where environmental degradation includes low soil fertility, advanced soil erosion and the prevalence of *talasiga* vegetation. However, at the time of european contact, the deltas of the south-eastern part of Viti Levu, see Figure 6.1, were the most densely populated areas in Fiji. Fortified villages were concentrated along the waterways to facilitate travel in the delta and hydrophytic crops were grown on the fertile alluvium of the delta flats, using complicated reticulated drainage channels and mounds. Speculation on the origin of the fortifications has included reasons for their construction, but little is known of the date of their origin, or of the impact of such settlements on the local environment. This study of vegetation history in the Rewa and Navua Deltas is intended to supply such information and to complement the emerging picture of human impact in the drier zones, presented in Chapter 5.

6.1 The Regional Setting 1: Rewa Delta

6.1.1 Physical Environment

The Rewa River is the largest river in Fiji and drains most of the eastern half of Viti Levu. Its delta is located 15 km north-east of Suva on the south-east coast of the island (Figure 6.1). The delta covers about 249 km^2, most of which is covered by alluvium deposited by the Rewa River, but 8000 ha are covered by mangrove swamp and 1000 ha are covered by peat swamp, see Figure 6.2. The surrounding hills are formed of Miocene-Pliocene Suva Marl (Geological Survey of Fiji 1966). The delta formation is abruptly underlain by marine and estuarine deposits which are approximately at present sea level (FAO/UNDP 1972a). The marine facies are coarse-medium sands composed mainly of quartz. Estuarine deposits often overly the marine facies, but occasionally coarse river deposits are sandwiched between. The estuarine material is characterised by its apparent deposition under anaerobic conditions, with frequent inundations by saline waters. Some decomposed organic material, which is apparently derived from mangrove vegetation is included in the dark grey sandy clay matrix (FAO/UNDP 1972a).

Figure 6-1: The Delta Regions of South-Eastern Viti Levu

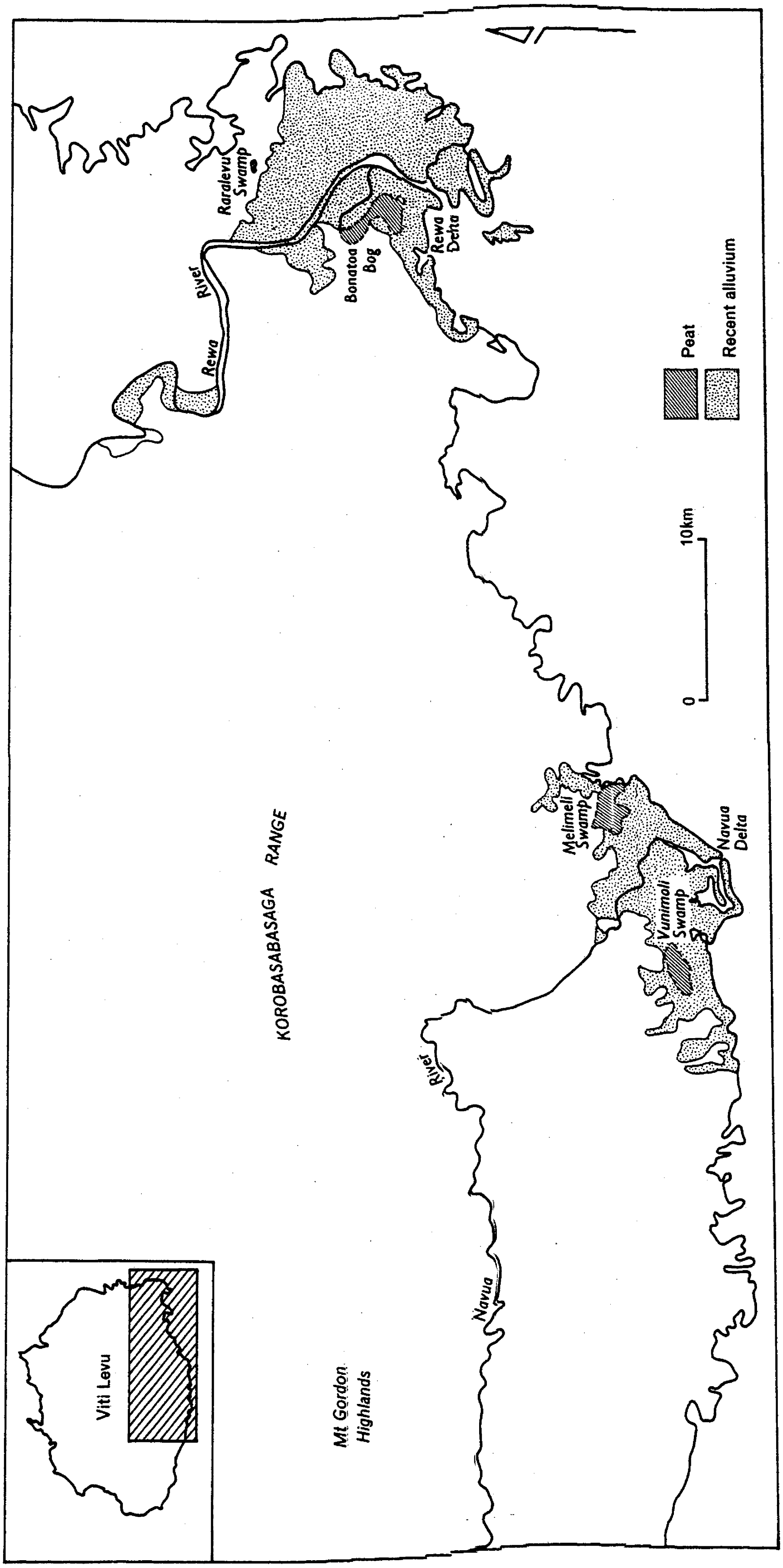
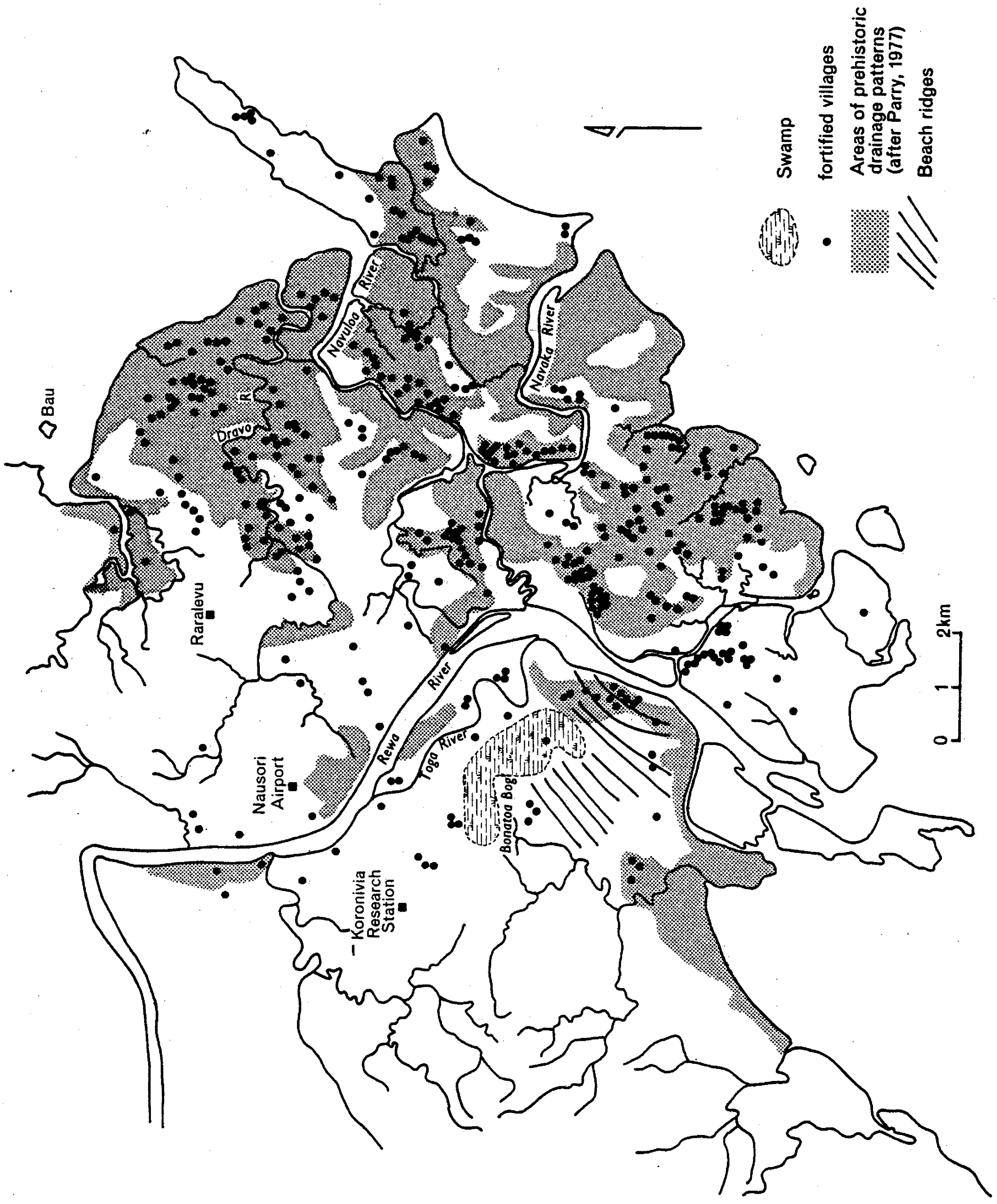


Figure 6-2: Major Features of the Rewa Delta



Soils in the delta region are determined by the average position of the water table and distance from the river and coast. Consistently high local water tables away from direct marine influences generally result in the accumulation of peat in the lowest inland sections of the delta. Towards the river channels there may be a mixture of peat and alluvial clay, with clay gradually dominating the substrate. Closer to the rivers the alluvium becomes coarser and includes a sand component which dominates on the levee banks that have built up along the main distributary channels of the delta (Twyford 1957).

The Rewa Delta, and the south-east coast of Viti Levu in general, receive moderately high rainfall. There is a weak dry season largely because the south-east trade winds continue to bring moisture laden air to the coast during the nominal dry season, from April to October. Rainfall records from Koronivia Research Station and Nausori Airport in the hills adjacent to the Rewa Delta are presented on Table 6.1 (see Figure 6.2 for their location).

Table 6-1: Rainfall in the Rewa Delta

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Koronivia	354	310	396	360	235	184	175	154	207	217	311	296	3199
Nausori	330	277	402	368	221	162	153	142	192	232	296	270	3045

(data, in mm, from Fiji Meteorological Service 1981)

The rainfall figures indicate that the total average annual rainfall of about 3000 mm in the delta falls mainly between October and March, with maximum monthly totals between January and April. These rainfall figures place the Rewa Delta within climatic zone E of Jenkins and Lesslie (1973). It has been noted, however, that the rainfall in the delta region is extremely variable and any month is likely to receive greater than 500 mm or less than 125 mm of rainfall (FAO/UNDP 1972a). Water tables on the inorganic soils of the delta may thus fluctuate dramatically, although the water-holding capacity of peats tends to maintain high water tables in the swamps, except after very long dry periods.

Temperatures in the region are far less variable and the average values (24.7°C and 24.8°C for Koronivia and Nausori, respectively) approach the average sea surface temperature for these latitudes in the south-west Pacific. The seasonal range of temperatures is slight, varying between about 22.6°C in July and 26.7°C in February (Fiji Meteorological Service 1982).

Large-scale floods of the Rewa River occur with a frequency of about one in every ten years, although high river levels occur at least once per year. The recurrence interval of catastrophic flooding, of a magnitude which would radically alter the distributary pattern of the delta, is estimated as in the order of 1000 years (FAO/UNDP 1972b).

6.1.2 Vegetation

The Rewa Delta has extremely fertile soils and as a result has been developed from prehistoric times as an area of high intensity agricultural activity. There is little of the original vegetation cover remaining.

Alluvial areas of the lower Rewa Valley supported large sugar cane plantations from the 1880s onwards, but the climate and drainage conditions eventually proved unsuitable for successful cultivation of this crop and the local mill at Nausori closed in 1959 (Ward 1965). At present the major large-scale crop is irrigated paddy rice. Drainage of small areas of peat has also occurred for the cultivation of rice.

The peatlands within the delta region are commonly covered with a mixture of sedges and grasses, for example, *Eleocharis ochrostachys*, *E. dulcis*, *Cyperus haspan*, *Pycreus polystachyos*, *Scleria polycarpa*, *Paspalum conjugatum*, and *Sacciolepis indica*. On the deeper peats (>1 m) *Pandanus pyriformis* is common, growing to about 5 m high, with an understorey of the ferns *Dicranopteris linearis*, *Lycopodium cernuum* and *Nephrolepis biserrata*, and a ground layer of *Sphagnum cuspidatum* (Ash and Ash 1984). A large proportion of the wetland species, especially those on the shallow peats, are recent introductions to Fiji.

Small patches of swamp forest remain at the margins of the peatlands and in the lee of beach ridges at the delta mouth. These consist of *Xylocarpus granatum*, *Phaleria* sp., *Barringtonia racemosa*, *Hibiscus tiliaceus* and *Inocarpus fagiferus* (FAO/UNDP 1972a; Ash and Ash 1984). The species composition is similar to that of the littoral forests around much of the Fijian coastline.

Mangrove vegetation is extensive at the mouth of the delta, with abundant *Rhizophora stylosa* at the seaward margin and *Brugiera gymnorhiza* along the creeks. These mangroves tend not to merge with freshwater wetland vegetation, but rather have an inland margin at the beach ridges.

The slopes surrounding the delta are cleared and planted with a variety of food crops, including breadfruit (*Artocarpus altilis*), taro (*Colocasia esculenta*), bananas (*Musa*), pineapples (*Ananas comosus*), and cassava (*Manihot esculenta*).

6.1.3 Human Impact

The earliest settlers in Fiji probably inhabited coastal sites and exploited the fish and shellfish resources of reefs and lagoons while maintaining a horticultural base of root and tree crops.

Most of the earliest dated archaeological sites in Fiji are on the northern and western coast of Viti Levu and small islands near these coasts. However, excavations on Naigani Island off the eastern coast yielded a date of 2860 BP (Kay

1984), which indicates that occupation probably occurred at suitable sites all around the coast from the time of earliest settlement, not just in the drier areas.

People gradually moved inland and continued their land-based economy using slash and burn techniques (Palmer 1969). At a later date there was a renewed phase of settlement at the coast, with a new settlement pattern centred on fortified villages. This new phase of coastal settlement was most firmly associated with the delta regions of windward Fiji, with evidence of large clusters of fortified villages in these areas.

Oral traditions reported by Parry (1977, 1981) suggest the settlers of the deltas were driven coastward by unrest amongst the inland populations at least six generations before european contact. Given Thomson's (1908) estimate of average Fijian generation length in the nineteenth century, this puts the arrival of settlers to the delta at about AD 1700 (Thomson 1908; Chapelle 1978). Parry arrives at a slightly earlier date for establishment of the fortifications based on a time scale constructed from the constrast marks on aerial photographs and the time taken for vegetation to reach equilibrium on abandoned ring-ditch sites. However, fortifications on Taveuni have been ^{14}C dated from 800 BP (Frost 1974) and on Lakeba such features date from at least 600 BP (Rowland and Best 1980); there is no reason why the Viti Levu sites should not be as old.

It was reported by Macdonald (1857) that 96 village sites were occupied in the Rewa Delta in 1856. The location of most of these sites is closely related to site conditions. The majority of villages were located on the alluvial and gley soils of levee crests, backslopes and edges of the backswamps, see Figure 6.2. These areas provided both protection from flooding and suitable soils for cultivation of swamp taro (*Cyrtosperma chamissonis*). Only one site was located on peat in the delta, but dense clusters of villages and extensive areas of former reticulated drainage occur at the edges of the peatlands and suggest a considerable prehistoric human impact on the environment. Disturbance of the wetlands has continued to the present with frequent burning of the vegetation on the swamps in recent years to allow access for grazing cattle. The surrounding slopes have also been subject to intensive modification for cultivation, largely to provide produce for the nearby markets of Suva and Nausori.

6.2 The Pollen Sites 1: Rewa Delta

Two sites within the Rewa Delta region were chosen for pollen analysis. The first, Bonatoa Bog, is the largest area of peat development in the delta (890 ha) and is the most likely to yield a long record of vegetation change. The second site is Raralevu, one of the smaller peat deposits located upstream in the delta and 7.5 km north-east of Bonatoa. The area has been drained for rice cultivation and the deep drainage ditches revealed a pattern of parallel channels infilled with peat within a clay deposit, and the whole overlain by a thin layer of peat. It is possible either that these were natural channels through the delta or that they were related to human activities. Prehistoric reticulated drainage patterns are clearly visible on aerial photographs of nearby areas, and it is possible that the latter explanation is more likely. An examination of the vegetation history at this site may reveal aspects of human impact on the delta environment.

6.2.1 Bonatoa Bog

The site is located about 15 km north-east of Suva, to the west of the main Rewa River channel, and 6 km north of the coast (Figure 6.2). Peat has accumulated at Bonatoa in a basin formed by low hills of Suva Marl to the west, the levee of the Rewa to the north, the levee of the Toga River (an anabranch of the Rewa) to the east, and by beach ridges to the south (Figure 6.3). Undoubtedly the origin of the site is related primarily to the post-glacial rise in sea level to present levels. It is hoped that the stratigraphy of the site and its vegetation history will reveal the role of sea level in the origin of Bonatoa and perhaps provide additional information on Holocene sea levels in Fiji.

Swamp vegetation

There are five vegetation types at Bonatoa, related to changes in the substrate from colluvium at the base of the slopes in the west, through to marginal peat, deep peat and alluvium near the levee on the eastern margin of the bog (Ash and Ash 1984). In addition, part of the central part of the bog had been recently burned. A quadrat approximately 4 m^2 was located in each of the vegetation types and a species list with species abundances was compiled and is presented below in Table 6.2, and their composition is discussed below.

There are strong similarities between the vegetation at the hillside and that at the levee margins of Bonatoa Bog. Dominant taxa in both areas are the grasses and sedges, including *Cyperus haspan* and *Brachiaria mutica* and herbaceous species including *Mikania micrantha*, *Cuphea carthagenensis*, *Ludwigia octovalvis*, and

Figure 6-3: Bonatoa Bog and Environs

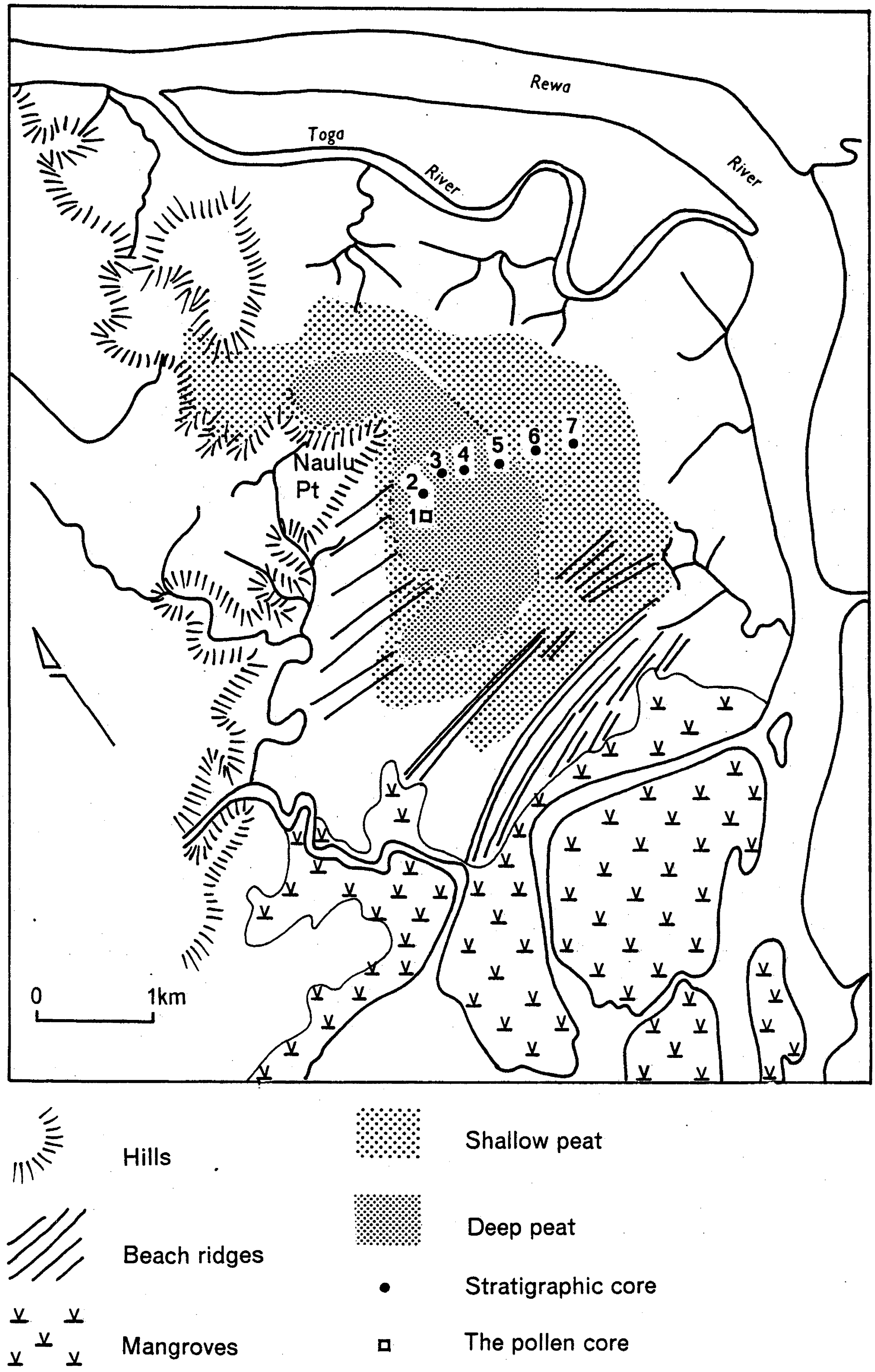


Table 6.2: Vegetation at Bonatoa Bog

Species	Sites				
	1	2	3	4	5
Bryophytes					
Sphagnum cuspidatum		+	++		
Pteridophytes					
Culcita straminea					+
Davallia fejeensis			+	+	
Dicranopteris linearis		+	++		+
Lindsaea ensifolia			+		
Lycopodium cernuum		+			+
Nephrolepis biserrata		++			+
Sphaerostephanos unitus		+			
Monocotyledons					
Cyperaceae					
**Cyperus difformis*					+
**Cyperus haspan*	++	++	++		++
**Cyperus pilosus*	+				++
Eleocharis ochrostachys	++		+++		
**Fimbristylis dichotoma*					+++
**Fimbristylis miliaceae*					++
**Kyllinga polyphylla*	+				+++
**Pycreus polystachyos*	+++	+++	++	++	+
**Rhynchospora corymbosa*	+				+++
Scleria polycarpa		+	++		+
Poaceae					
**Brachiaria mutica*	+++				+++
**Dicanthium caricosum*					+
**Echinochloa colona*					+
**Eragrostis unioloides*	+		+		+
**Paspalum conjugatum*					+++
Paspalum orbiculare			+	+	+++
**Sacciolepis indica*	++		++	+	+
Pandanaceae					
Pandanus pyriformis			+++	++	
Orchidaceae					
Spathoglottis pacifica					

Sites: 1 = Colluvium at foot of hills
2 = Margin of peat swamp
3 = Unburned *Pandanus* swamp
4 = Burned *Pandanus* swamp
5 = Alluvium near river levees

* = European introduction
\+ = present ++ = common +++ = abundant

cont'd.

Table 6.2 cont'd

Species	Sites				
	1	2	3	4	5
Dicotyledons					
Shrubs & trees					
**Brassaia actinophylla*		+		+	
Hibiscus diversifolius				++	
**Piper aduncum*		+		+	
**Solanum torvum*		+			
Herbs & creepers					
**Borreria laevis*		+			+
Cassytha filiformis					+
Centella asiatica					+
**Clidemia hirta*			+		+
**Crassocephalum crepidioides*		+	+		
**Cuphea carthagenensis*	++				++
Derris trifoliata	+				+
**Hyptis pectinata*		+		+	
**Ludwigia octovalvis*	+++				++
Melastoma denticulatum	++		+	+	+++
**Mikania micrantha*	++		+	++	+++
**Mimosa pudica*	++				
**Passiflora foetida*		+			
**Polygala paniculata*				+	

Melastoma denticulatum. On the peaty substrates, *Pandanus pyriformis* dominates with an understorey of the sedges, *Eleocharis ochrostachys*, *Pycreus polystachyos*, and *Scleria polycarpa* and a ground cover of *Sphagnum cuspidatum*. The major change in this community after fire is the destruction of the *Sphagnum* ground layer and a reduction in species diversity. The *Pandanus* community merges with the vegetation communities at both ends of the soil catena.

Taxa which are common at the margins of Bonatoa Bog are largely european introductions which are invading from the hillslopes and the cultivated levee banks. On the peat bog proper there remains a high proportion of native taxa, although two of these (*Paspalum orbiculare* and *Hibiscus diversifolius*) may be aboriginal introductions (Parham 1959; Smith 1981). Continued burning on the bog may allow the invasion of more introduced taxa and the destruction of what appears to be a fairly sensitive community of *Pandanus*, *Sphagnum* and sedges.

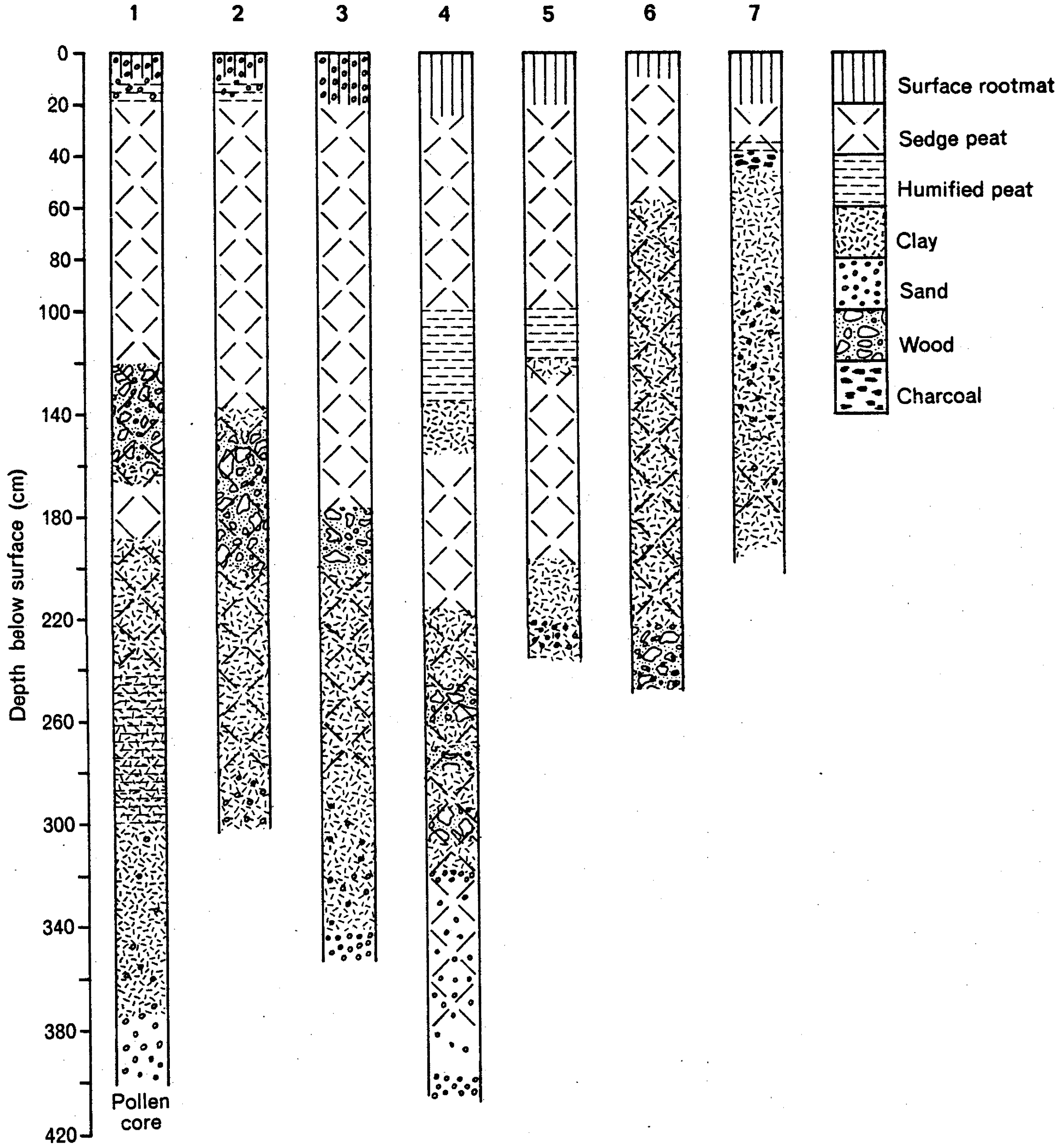
Stratigraphy of the site

A transect of stratigraphic cores was collected at Bonatoa using a hand-held D-section corer. The transect passed from the marginal peats in the east of the site to the base of the hillslopes and from there south to the deeply developed peats on the main part of Bonatoa Bog (see Figure 6.3 for their location). The stratigraphic profiles for the cores are presented on Figure 6.4. Material has accumulated to a maximum depth of about 4 m and there is a similar stratigraphic sequence in all of the cores. The sequence is characterised as follows.

1. There is a surface layer of roots and shoots of living plants, which is slightly humified and incorporates charcoal from recent fires.
2. The surface root mat passes gradually into highly organic fresh peat which consists mostly of sedge roots and shoots. The peat layer shallows near the eastern margin of the bog, but increases in depth towards the western margin and to the south. There are often inclusions of wood and clay.
3. The peat becomes more humified with depth and gradually merges with underlying clays.
4. The basal material in all cores consists of a mixture of clay and sand-sized particles becoming dominated by sand and impenetrable with the D-section corer with increasing depth.

The stratigraphic sequence of the north-eastern part of the bog has been described and interpreted by Adams (1970). He suggests the stratigraphy represents the following sequence of events: reclamation of land from the sea by mangroves subsequent to sea level rise; impeded freshwater drainage; and the establishment of peat producing swamp vegetation. The sedimentary sequences from Bonatoa

Figure 6-4: The Stratigraphy of Bonatoa Bog



reported here also seem to suggest these events have contributed to the formation of the site. To ascertain the relationship of Bonatoa with present sea level and its likely relationship with the origin of the bog, the site was surveyed with an automatic level from the trig. datum on Naulu Point. The levelling was related to the pollen core (Core 7 on Figure 6.4) and gave a surface height at that point of 4.62 m above mean sea level (msl), which places the base of the core at approximately present sea level and the start of peat formation at 1.87 m above msl.

It therefore seems likely that formation of the swamp began with the arrival of the sea at about its present level. Pollen analysis of the core, related to the ^{14}C dating, will allow a more complete discussion of the development of the site and will be attempted below.

The pollen diagram

The pollen core was collected in 50 cm sections by D-section corer as described above for Tagimaucia and Nadrau, wrapped and sealed in plastic in PVC tubing. In the laboratory the core was sampled at 20 cm intervals. The material was used for organic determinations and prepared for pollen analysis following the standard techniques described above. The core had dried out considerably and therefore no attempt was made to determine the moisture content of the material. Pollen counts proceeded until 200 grains had been recorded, which formed the pollen sum. Pteridophytes were also recorded, but excluded from the pollen sum. Carbonised particles were recorded from the same samples using the point count method of Clark (1982) with a relative error of 25%, and they are expressed as mm^2 cm^{-3}.

Sediments for ^{14}C dating were extracted from significant stratigraphic breaks in the core at 380 to 390 cm (the appearance of fine organic material), 275 to 300 cm (the change to humified peat) and 140 to 150 cm (the change to fresh peat formation). An additional sample from 230 to 250 cm was submitted when the 275 to 300 cm sample gave a modern result.

^{14}C dating and stratigraphy of the pollen core

The following dates were reported for this core:

Code No.	Depth in core (cm)	Reported date (yrs BP)
ANU-3814	140 - 150	1470+/-100
ANU-3813	230 - 250	2290+/-75
ANU-3815	275 - 300	>M(106.1+/-1.4%M)
ANU-3816	380 - 390	4360+/-180

The modern result from ANU-3815 is most likely to have resulted from contamination by younger material as the core was extracted; probably from the outside of the D-section corer. It seems unlikely that younger carbon has been incorporated from above since there was no evidence of growing rootlets in the material and the dates from higher in the core fall in chronological order. The material for ANU-3813, taken immediately above ANU-3815, is very similar in composition to the contaminated sample, and did not yield an anomalous result.

These dates suggest that the accumulation rate in the early phase of development at Bonatoa Bog was about 1 m 1400 yrs^{-1}, increasing to 1 m 900 yrs^{-1} above about 250 cm in the core. This coincides with the change to more organic and fibrous sediments.

The stratigraphy of the pollen core is shown on the pollen diagram, Figure 6.5,
adjacent to the ^{14}C dates and the organic determinations. The core is described below.

0 - 10 cm	There is a root mat of extant surface vegetation, including sedges and *Sphagnum* moss with some charcoal inclusions. Organic content is high (85 to 90%).
10 - 125 cm	The root mat merges with the underlying fresh peat, which has obvious sedge root and shoot remains. Organic content is consistently above 90% in this layer.
125 - 160 cm	This is fresh sedge peat as above, but mixed with woody fragments, possibly *Pandanus*. The peat shows some humification from 140 to 150 cm.
160 - 162 cm	A thin band of yellow/brown clay, showing abrupt boundaries with the peat above and below. Organic content falls to about 45% in this layer.
162 - 270 cm	The peat becomes increasingly humified and the clay content increases with depth. There is a second narrow clay horizon at 200 cm. Organic content fluctuates in this horizon, but decreases overall to about 20% at the base.
270 - 300 cm	This is a brown clay with some woody fragments and sedge roots and shoots.
300 - 400 cm	The basal sediment is dominantly grey/brown clay with increasing sand content from 340 cm. At the base there is little or no clay. Organic content is low, averaging about 15%.

Zonation and description of the pollen diagram

The fossil pollen spectra from Bonatoa Bog are presented on Figure 6.5 as percentages of the pollen sum of 200 pollen grains. Pteridophyte taxa were calculated on the same basis, but their counts were excluded from the pollen sum. The pollen diagram also includes the carbonised particle counts. It has been divided into three zones as follows.

B3 400 - 300cm	The basal zone has very high representation by *Metroxylon vitiense*. Common forest taxa include *Calophyllum*, Myrtaceae, *Dillenia*, Arecaceae, *Plerandra*, *Podocarpus*, and *Palaquium*, most of which have their highest representation for the whole sequence.

Figure 6-5: Bonatoa Bog: Percentage Pollen Diagram

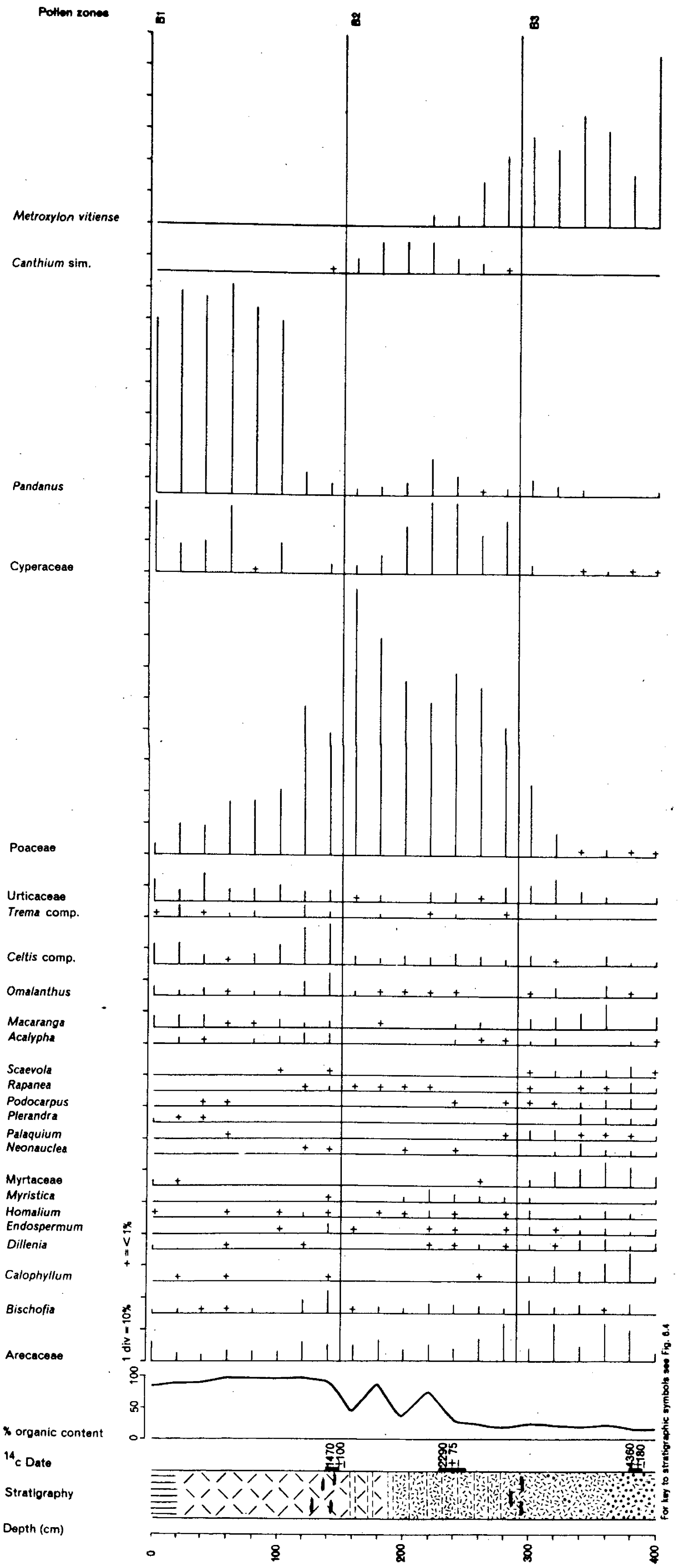
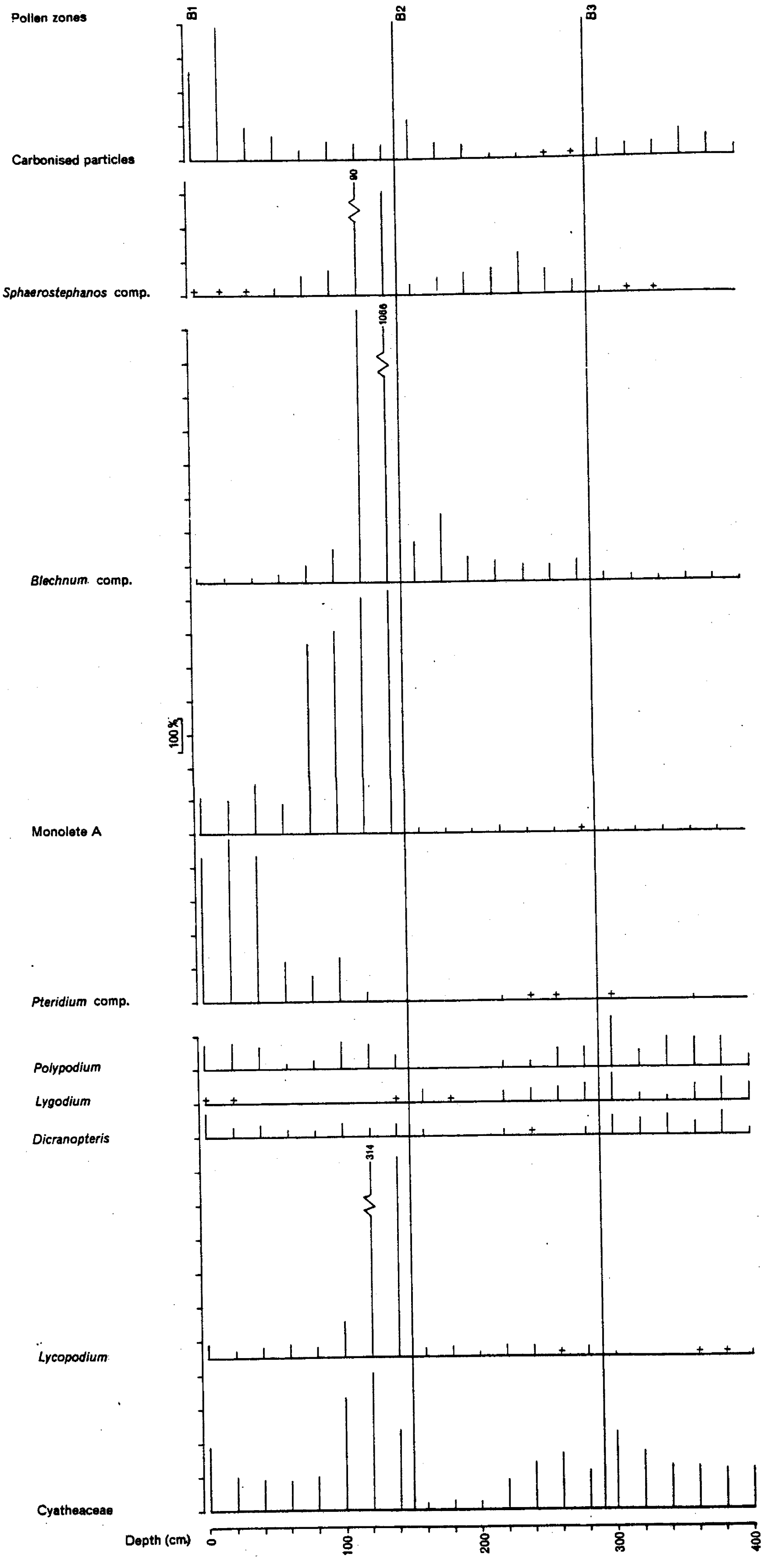


Figure 6-5 cont'd



	Cyatheaceae, *Polypodium*, *Lygodium* and *Dicranopteris* have sustained representation in this zone.
B2 280 - 160 cm	*Metroxylon vitiense* declines markedly at the beginning of this zone and then disappears from the pollen record. *Canthium* sim. is represented almost exclusively in this zone and Cyperaceae increases. Very high values for Poaceae are evident, but several forest taxa are severely reduced (e.g. *Calophyllum*, Myrtaceae and *Palaquium*). Arecaceae, *Celtis* and *Bischofia* maintain consistent representation. Pteridophytes generally decline in zone B2, although *Blechnum* comp., *Lycopodium* and Monolete A become more common.
B1 140 - 0 cm	The upper zone is marked by high values for *Pandanus*, declining representation by Poaceae and increased representation by *Celtis* comp., *Trema* comp., Urticaceae, *Macaranga*, *Omalanthus*, and *Acalypha*. There is a steady increase in *Pteridium* comp. and extremely high values for *Lycopodium* at the base of the zone, although these decline towards the top.

Discussion

The basal sediments in the pollen core are inorganic, largely clay, and were deposited at about 4300 BP. They are close to present sea level and probably began accumulating as present sea level was achieved and the delta region was inundated. While the composition of the sediments indicates accumulation in a mangrove environment, as Adams (1970) suggests, the swamp pollen spectra suggest a very different local picture. The swamp pollen spectra throughout zone B3 are dominated by *Metroxylon vitiense*, the sago palm, in percentages approaching those of modern surface samples from within sago swamp. The presence of *Lygodium* at these levels is also similar to modern sago swamp samples. It is therefore likely that Bonatoa was supporting sago swamp from at least 4300 BP to about 2500 BP.

While *Metroxylon* has been recorded inhabiting sites with a marine influence, and shown experimentally to withstand salinity levels of up to 5 parts per 1000 (cf. 35.5 parts per 1000 for seawater; Flach *et al.* 1977), it has also been noted that exposure to intertidal conditions results in stunted growth, debilitated sucker development, and a reduction in flowering. Optimal conditions for growth are suggested to include regular inundation by fresh water in shallow swamp conditions to provide nutrients and exclude competitors (Paijmans 1980; Rhoads 1982).

The pollen spectra indicate the presence of a sago swamp similar in character to that presently occupying sites at the inland margin of the Navua Delta. It seems likely that freshwater, or marginally saline conditions prevailed, which is not consistent with the notion that the Bonatoa area and perhaps the whole of the Rewa Delta was open to the sea. The beach ridges at the seaward margin of Bonatoa must have been in place at this time and freshwater drainage already impeded. The inorganic nature of the sediments and the requirements for sago growth suggest that a strong fluvial influence was present and that the levee banks were not yet fully developed.

The carbonised particle values are moderately high at these levels. Possibly this is the result of a high water-borne influx of carbon resulting from fires in the catchment area if the river was occasionally flooding. However, dryland pollen spectra at these levels indicate that a diverse forest of *Calophyllum*, Myrtaceae and Arecaceae with *Bischofia*, *Dillenia*, *Plerandra*, *Podocarpus*, *Endospermum* and *Palaquium* existed in dryland environments near the swamp, similar in composition to forests described by Berry and Howard (1973) for subcoastal areas at present. Climatic conditions in the catchment were thus likely to have been comparable with the present, that is, high annual rainfall, evenly distributed throughout the year, and it is unlikely that natural fires were occurring in the catchment under these conditions. Alternative explanations include fires on the swamp surface, or that burning in the catchment was the result of human interference. Given the extremely wet conditions which probably prevailed at Bonatoa at this time, the latter explanation seems more likely.

While anthropogenic burning may have been occurring in the catchment from about 4300 BP, there is no major change in the dryland vegetation until about 3000 BP. At this time several forest taxa indicative of disturbance (e.g. Urticaceae and *Macaranga*) increase in representation as the forest taxa, *Calophyllum*, Myrtaceae, *Plerandra*, *Podocarpus* and *Palaquium*, decrease and virtually disappear from zone B2. Poaceae then becomes far more common and dominates the pollen spectra.

The swamp vegetation changes dramatically at about the same time. *Metroxylon* declines and then disappears from the record, *Pandanus* and Cyperaceae become common for the first time and *Canthium* sim. appears in the pollen spectra and shows a small peak. The sediments become increasingly organic, no doubt due to the presence of peat-forming sedges.

The exclusion of *Metroxylon* from the vegetation is probably the result of several developments at the swamp. Firstly, there may have been a reduction in fluvial inundation. Possibly levees built up along the nearby channels and fresh water drainage was severely impeded such that peat-forming taxa (e.g. sedges) could invade. Once organic accumulation occurs, *Metroxylon* is disadvantaged. It has been noted that stands of *Metroxylon* become stunted during transitions to herbaceous peatswamp (Paijmans 1980) and have longer maturity periods and lower yields when growing on a peaty substrate (Tie and Lim 1977).

The build up of levees may have been a direct result of the postulated anthropogenic disturbance in the catchment. The forest apparently declined in diversity in the immediate vicinity of Bonatoa at this time and disturbance taxa became more common. The subsequent increase in Poaceae suggests that the dryland vegetation became more open and runoff likely to carry a greater sediment load. This would have no doubt contributed to the construction of levees along the river channels. The carbonised particle curve shows reduced concentrations in the lower half of zone B2, which may be partly a reflection of a reduction in fluvial input to the site; that is, carbonised particles from the catchment were not being washed onto Bonatoa. There are none of the very high values which are usually associated with local fires (Clark 1983).

The apparently simultaneous changes in both dryland and swamp vegetation are worthy of note. The presence of man in the area is strongly suggested by developments in the dryland vegetation; it is possible that the decline in *Metroxylon* pollen is not reflecting the disappearance of this taxon from Bonatoa, but is rather a reflection of its exploitation by humans. In Fiji at present, sago fronds are used extensively as roof thatching, but the pith is not prepared for consumption as it is elsewhere in Melanesia. In natural stands of *Metroxylon* the palms grow to maturity in seven to fifteen years, flower once and then die. The maximum amount of starch in the stem is present immediately prior to flowering; during the reproductive phase the starch is expended, so that harvesting occurs before the plant has flowered. Vegetative reproduction occurs from a massive rhizome at the base of mature plants (Kiew 1977). As a result, where a sago swamp is being harvested for human consumption, little or no pollen is likely to be produced. It is certainly possible that the population in the Bonatoa area was exploiting the sago swamp and if so this occurred from about 3000 BP, although it may have been occurring in a more limited manner from about 4000 BP. As noted above, this coincides with increased human activity in the catchment and would be consistent with intensification of all agricultural practices.

Other swamp communities are indicated as growing nearby at the same time. Sparse *Pandanus* is indicated with an understorey of sedges and possibly grasses somewhere in the vicinity of the pollen site. *Canthium* sim. may have also been a component of the vegetation. In Fiji this taxon is usually a shrub of the forest edge and has not been observed as a component of swamp vegetation, although it has been recorded growing in swamps inland of mangroves in Malaysia (Morley 1981).

It is notable that at present there are few open swamp communities in Fiji which are not maintained by fire (Ash and Ash 1984). The Lake Tagimaucia basin may be one of the few exceptions. Since fire seems unlikely on the swamp during zone B2, it is possible that taxa excluded from swamp vegetation at present because of frequent burning (possibly including *Canthium*) may have been able to colonise Bonatoa at this time.

Carbonised particle concentrations increase at the top of the zone and continue as high values in zone B1, which may be indicative of intensive burning on the swamp surface. Certainly several swamp taxa are reduced, including Cyperaceae and *Canthium* sim., and *Metroxylon* disappears. The swamp vegetation may have then been dominated by pteridophytes, although it is not certain which fern taxa were involved.

This period may mark a change in human activity at the site. The increasing organic content of the sediments suggests *Metroxylon* was less suited to prolific growth on Bonatoa and probably disappeared from the local vegetation quite naturally. There may have been a shift in agricultural activity once the *Metroxylon* food source had diminished. Irwin (personal communication 1986) has suggested that the fortifications in the Navua Delta may date from about 1500 BP and it seems likely that the Rewa Delta sites are at least as old. The close relationship between such fortifications and the development of intensive wetland cultivation was discussed above. The change in the swamp vegetation and the increase in local fires at Bonatoa Bog dates from about 1400 BP and this may be a record of the change in human activity from cultivation and exploitation of naturally available resources, to one in which the environment near Bonatoa was manipulated to allow intensive agriculture, such as the development of complicated wetland drainage systems. While the build up of sediments at Bonatoa may have been unfavourable for *Metroxylon*, conditions may have improved for other food crops. The Rewa Delta fortified villages may also therefore date from this time.

In zone B1, from about 1400 BP, the swamp vegetation is dominated by *Pandanus* and possibly pteridophytes, and the substrate becomes extremely organic and peaty. Sedges were probably present as an understorey.

Dryland taxa which are common include *Celtis* comp., *Trema* comp., Urticaceae, *Macaranga*, *Omalanthus*, and *Acalypha*, but there are few primary forest taxa represented. Poaceae decreases in representation, but this may be partly due to its exclusion from the swamp surface. It seems likely that, if exploitation of wetland resources was increasing, human activity in dryland habitats may have diminished, allowing for the partial recovery of dryland vegetation.

Carbonised particles increase dramatically in the top 80 cm of the deposit which covers the past 700 years or so. This suggests that fires probably extended across the swamp at frequent intervals during this time. The initiation of such activity may indicate a period of more intensive use of the Bonatoa area, perhaps related to increasing populations in the area and a greater demand for food resources.

6.2.2 Raralevu

This site is located 7.5 km north-east of Bonatoa Bog, on the eastern side of the main Rewa River channel, Figure 6.2. It is one of the small peat deposits which occur in the upper part of the Rewa Delta. Raralevu was examined in 1983 as part of a vegetation survey of the wetlands of Viti Levu (Ash and Ash 1984), at a time when the site was being drained and prepared for paddy rice production. The deep drains which cross the site revealed a pattern of apparently parallel channels filled with peat within a larger alluvial deposit, the whole overlain by peat, see Figure 6.6. Aerial photographs reveal the vestiges of prehistoric reticulated drainage patterns, probably for growing taro and swamp taro, nearby (Parry 1977) and it was thought that the peat filled channels might also be remnants of former intensive agricultural activity.

A shallow layer of peat covers the area, presumably because of impeded drainage on this flat, low-lying part of the delta. The swamp is bounded on its northern and eastern margins by low hills of Suva Marl which protrude onto the alluvial plain, and to the south by a low levee of Waidamu Creek.

The local vegetation is much disturbed by a long period of intensive agricultural activity, including the present rice growing scheme. All plant taxa growing at the site were collected and identified and the following species list presented on Table 6.3 reveals the abundance of introduced taxa. The slopes to the north and east have also been cleared for food crop production and are now covered either with these food crops or with the native reed, *Miscanthus floridulus*, in areas of abandoned crop production.

Stratigraphy of Raralevu

The general stratigraphy of the site was observed from the exposures in the drainage ditches. The surface layer consists of a root mat about 5 cm deep. Beneath this in the peat channels there is approximately 70 to 80 cm of fibrous sedge peat; in the sections between channels the peat is much shallower, about 20 cm. The peat is underlain by grey/brown silty clay, probably alluvial, incorporating some organic, fibrous material. This layer was of an undetermined depth.

Samples for pollen analysis were collected from the cleaned face of one of the deepest peat channels in 10 cm sections. These were sealed in plastic bags and

Figure 6-6: Stratigraphic Exposure at Raralevu

Table 6-3: Vegetation at Raralevu

Species Present

Pteridophyta
Dicranopteris linearis
Lindsaea ensifolia
Lycopodium cernuum
Monocotyledons
Cyperaceae
•*Cyperus haspan*
•*Cyperus pilosus*
Eleocharis ochrostachys
•*Fimbristylis miliaceae*
•*Kyllinga polyphylla*
•*Pycreus polystachyos*
Poaceae
•*Brachiaria mutica*
•*Echinochloa colona*
•*Eragrostis unioloides*
•*Paspalum conjugatum*
Paspalum orbiculare
•*Sacciolepis indica*
Commelinaceae
Aneilema vitiensis
Dicotyledons
•*Cuphea carthaganensis*
•*Ludwigia octovalvis*
•*Mikania micrantha*

• = european introduction

labelled. In the laboratory, a 1 cm^3 sample was extracted from the centre of each for pollen analysis and prepared in the usual manner. Organic determinations were made on the remainder of the samples. Pollen counts proceeded until 200 dryland pollen grains had been recorded and this formed the pollen sum. Pteridophyte taxa were excluded from the sum, but calculated on the same basis. Carbonised particle concentrations were estimated from the same samples using the point count method.

A piece of wood lying *in situ* at the top of the clay layer at 80 to 100 cm was extracted, cleaned, dried and submitted for ^{14}C dating. The reported date of 2070+/-90 BP (ANU-4559) represents the transition from inorganic to organic accumulation at Raralevu.

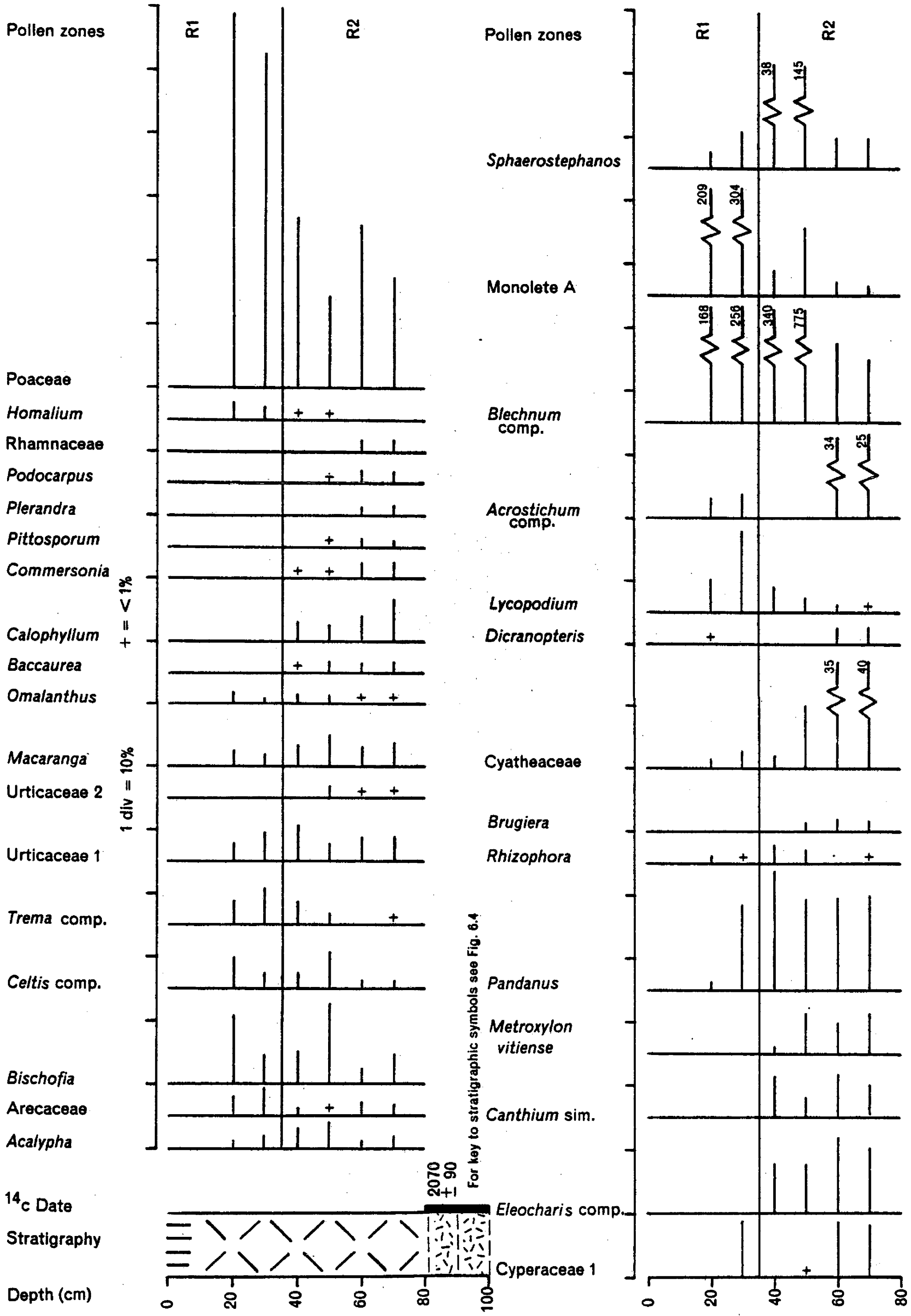
The pollen diagram

The percentages of fossil pollen types from Raralevu are presented on Figure 6.7. The diagram also includes the stratigraphic column and ^{14}C date.

The diagram has been divided into two local pollen zones and these are described below.

R2 80 - 40 cm This zone is characterised by the presence of several forest taxa, including *Baccaurea*, *Calophyllum*, *Commersonia*, *Pittosporum*, *Plerandra* and *Podocarpus*. The values of all these taxa decline towards the top of the zone. Poaceae increases in zone R2. Swamp taxa are represented by Cyperaceae 1, *Pandanus*,

Figure 6-7: Raralevu: Percentage Pollen Diagram



Eleocharis comp., *Canthium* sim. and *Metroxylon vitiense.* The latter three appear only in this zone. Cyatheaceae has high values at the base, but decreases towards the upper zone boundary. *Blechnum* comp. and *Sphaerostephanos* comp. have very high values, especially towards the top of zone R2.

R1 30 - 0 cm The upper zone is marked by the absence of the forest taxa mentioned above. *Acalypha*, *Bischofia*, *Celtis* comp., *Trema* comp., *Macaranga* and Urticaceae 1 are common. Poaceae increases to its maximum representation. Swamp taxa show a general decline in representation, but there is a very large increase in the ferns *Blechnum* comp. and Monolete A.

Discussion

The Raralevu record covers the period from about 2000 BP to the present. Throughout this time the site is an established peat swamp. Pollen preparations from the underlying clays revealed very low concentrations of badly preserved pollen grains and no meaningful pollen counts could be obtained.

The earliest recorded swamp vegetation at Raralevu consists of *Pandanus* and sedges, perhaps with some *Canthium* sim. The carbonised particle concentrations are suggestive of background values and it seems unlikely that burning was occurring on the site. The *Metroxylon* values at these levels (about 5%) are probably representative of sago swamp growing nearby, perhaps at the base of the surrounding slopes, rather than on Raralevu itself. It is possible that the inorganic material beneath the peat supported *Metroxylon*, but this is speculative. The vegetation and the environmental conditions are probably similar to those prevailing at Bonatoa from about 3000 to 1400 BP.

Acrostichum comp. is present in quite high values at the base of zone R2. *A. aureum* has been noted in Fiji as a component of the vegetation at the inland margin of mangroves and extending as a dominant species inland to freshwater conditions (Ash and Ash 1984). The presence of low percentages for the mangrove taxa *Rhizophora* and *Bruguiera* probably indicates mangrove communities in the vicinity of Raralevu and the *Acrostichum* may have been forming the inland margin as it does at present.

Dryland vegetation in this period is represented by several pollen taxa, including *Calophyllum*, *Baccaurea*, *Commersonia*, *Pittosporum*, *Podocarpus* and *Cyathea.* The pollen spectra are similar to those at Bonatoa prior to about 3000 BP, and suggestive of the forest described by Berry and Howard (1973) for subcoastal areas in the region at present. The presence of several woody taxa indicative of disturbance (e.g. *Bischofia*, *Celtis* comp., *Macaranga* and Urticaceae) and high values for Poaceae suggest that some disruption of the forest cover had taken place by about 2000 BP, but either not of the same extent as that which took place near Bonatoa at about 3000 BP, or perhaps this represents recovery after an earlier phase phase of forest clearance. Extensive deforestation apparently took place near Raralevu at about 1000 BP, marked by an increase in Poaceae and a peak in carbonised particles. Taxa indicative of disturbance remain in zone R1, with *Trema* comp. showing an overall increase in representation.

The swamp vegetation also changes after about 1000 BP, which suggests the very high carbonised particle concentrations may be indicative of fires on the swamp itself. All swamp taxa decline in representation or disappear from the record. Since peat continues to be deposited some form of swamp vegetation must have persisted at the site. The very high percentages for the pteridophyte taxa, *Blechnum* comp., Monolete A and *Lycopodium* suggests these may have formed the swamp vegetation from this time, perhaps augmented by Poaceae. This vegetation probably persisted at Raralevu until the recent drainage for rice cultivation. Such fern and grass communities have been observed in the Navua Delta at present (see below 6.3.2).

The origin of the Raralevu channels remains unclear. If the channels are of anthropogenic origin then their use must pre-date 2000 BP. The fact that they have subsequently been infilled with peat suggests abandonment since 2000 BP. Human activity in the Rewa Delta region is indicated from the Bonatoa record from probably 4000 BP, so the presence of man at Raralevu by at least 2000 BP is likely.

The cultural assemblages from the earliest archaeological sites in Fiji include artefacts indicative of an agricultural component to the resource base (Green 1974; Kirch 1979). Knowledge of wetland irrigation procedures probably formed one of the original settlers' agricultural practices (Spriggs 1985) and Palmer (1969) suggests this may have led ultimately to the form of the fortifications in the delta region. Aerial photographs reveal extensive areas of abandoned reticulated drainage near Raralevu, which Parry (1977) suggests date from the early nineteenth century although he indicates settlement without intensive agriculture may have occurred earlier. This probably does not allow enough time for the development of fortifications as suggested by Palmer (1969). Since the vegetation records from Bonatoa suggest human activity in the region in terms of vegetation clearance and burning from at least 3000 BP and possibly 4000 BP, some form of agricultural activity is also likely from this time. The drainage patterns which show up on aerial photographs may well be the most recent systems, but the ditches at Raralevu may be much earlier evidence of such activity.

While there is no evidence in the vegetation record which confirms an anthropogenic origin of the channels, it is difficult to ascribe their formation to natural causes. They may have been channels through mangroves, maintained by tidal scouring, but Raralevu is quite removed from marine influences at present and it is unlikely that there has been a greater marine influence in the past 4000 years or so, if the Bonatoa data on sea levels and land building are correct. The clays are more likely to be alluvial and deposited during flood peaks of the Rewa system. Parry's (1977) analysis of the relationship between the drainage systems and site characteristics showed that the most intensive wetland agriculture was centred on the alluvial soils of the crests and backslopes of levees. Raralevu at about 2000 BP was probably located on the backslope of a small levee of Waidamu Creek and may have been an ideal site for wetland cultivation. The subsequent infilling of peat may have been due to abandonment of the site and the invasion of peat forming taxa. Parry (1981) noted that ring-ditch fortifications abandoned after the measles epidemic of 1875 were quickly colonised by sedges and filled with peat.

The reason for abandonment of Raralevu is speculative, but it may have been related to changes in the distributary pattern of channels in this part of the Rewa Delta due to catastrophic flooding. Parry (1977) noted that the main distributaries of the Rewa system have previously flowed out to the east of the delta system; the present main Rewa channel was not assumed until the late eighteenth century. Similar changes in the overall drainage system undoubtedly took place in the past and may have affected the suitability of Raralevu for agriculture. The most recent reticulated drainage system in the area is located much further to the east of Raralevu and the shift may have been in this direction from Raralevu.

Since about 1000 BP there seems to have been increased deforestation of the catchment, which is probably related to human activity. Palmer (1969) suggests that increased hostility in the delta region forced defeated groups to move inland and possibly clearance would have occurred as they moved.

6.2.3 Environmental Change in the Rewa Delta

Sea levels

The evidence from the Bonatoa Bog sediments, ^{14}C dates and pollen spectra suggest that this part of the delta at least was cut off from the direct influence of the sea by about 4300 BP. *Metroxylon vitiense* swamp was established at the site by this time and the preferred environmental parameters for its growth suggest conditions were probably freshwater, or at most slightly brackish, with a sustained fluvial input to the site. These data suggest two things: firstly, the beach ridges on the seaward margin of Bonatoa had already formed and were an effective barrier between the site and marine influences; and secondly, the river levees had probably not yet built up in the area near Bonatoa Bog.

It is likely that Bonatoa was an estuarine flat prior to the build up of the beach ridges and the sediments below 4 m in the core were sampled for their pollen content as a means of establishing whether mangrove conditions persisted in the area. Unfortunately, the material yielded very low concentrations of badly preserved pollen and gave little indication of the vegetation which might have occupied the delta at the time the sediment was deposited. However, the nature of the sediments (fine clays mixed with marine sands and a little organic matter), coupled with the fact that the pollen was badly eroded, may suggest that mangrove conditions did prevail at the time. It has been noted that mangrove systems are open and that pollen is preserved only under exceptional circumstances (Grindrod in press). The marine sands in the sediments indicate tidal flushing was occurring, and surface samples from Lautoka (see above 3.2) showed very poor pollen preservation under such conditions. Bonatoa may therefore represent a site in which the conditions for pollen preservation were not met.

The beach ridges probably formed as sea level rose, and by 4300 BP they were protecting the Bonatoa area from the sea. The ridges consist of clay overlying and mixing with sands. Roy investigated the ridges and suggests that the ridges were originally highly feldspathic sand, as would be expected from the geology of the catchment, and that the clay has formed *in situ* as a product of rapid feldspar weathering in the humid tropical climate (P. Roy personal communication 1986). Their formation tends to indicate that the sea reached its present level by about 4000 BP. The data from the Navua Delta was interpreted as indicating present sea level was reached by at least 1600 BP (Ash and Ash 1985), and the Bonatoa data do not necessarily contradict this conclusion, assuming that any sea level change between 4000 and 1600 BP was of a minimum amount. It is likely that the Bonatoa beach ridge sequence was constructed before 4000 BP, as all ridges are substantially weathered. There is no evidence from either Bonatoa or Raralevu to suggest higher sea levels in the past 4000 years.

Development of the vegetation

The earliest record of the dryland vegetation in the Rewa Delta is contained within the Bonatoa Bog sediments. From about 4300 to 3000 BP the slopes surrounding Bonatoa probably supported a diverse forest, similar in composition to the small patches of undisturbed forest which remain in subcoastal parts of Fiji. Species of Myrtaceae, Sapotaceae, and Arecaceae with *Calophyllum*, *Bischofia*, *Dillenia*, *Podocarpus* and *Endospermum* were common. This indicates that climatic conditions were similar to the present in the area from at least 4300 BP.

There are high enough concentrations of carbonised particles in these basal samples to suggest that some burning was occurring in the catchment, but no major changes in the dryland vegetation are recorded until about 3000 BP. At this time the Poaceae and secondary forest taxa increase in importance at the expense of forest taxa. Deforestation had obviously occurred in the vicinity of Bonatoa Bog and such conditions have been sustained until the present.

Deforestation apparently did not occur throughout the Rewa Delta area at this time, because the Raralevu pollen diagram indicates forest persisted nearby until about 1000 BP. The pollen spectra do suggest, however, that forest disturbance had probably occurred within the greater catchment area of the site by 2000 BP. Extensive deforestation is evident in the Raralevu area at about 1000 BP, when most forest taxa disappear and Poaceae increases in abundance.

At Raralevu high carbonised particle concentrations coincide with the major phase of deforestation, which suggests the vegetation cover was destroyed by fire. At Bonatoa the carbonised particles decrease in abundance as forest taxa reach their lowest levels, but this need not contradict the postulated relationship between fire and deforestation. There may have been a gradual decimation of the forest through zone B3, and the high carbonised particle concentrations in these levels suggest fire was the destructive agent. There was then a gradual increase in the abundance of secondary forest taxa, towards the top of zone B3 (ca. 3000 BP). Forest clearance probably increased surface erosion in the catchment and caused enough sediment transport in the river system to form the levees. This would have reduced fluvial input to the site, including water-borne carbonised particles from catchment fires. A reduction in the abundance of carbonised particles might be expected even if fires continued at the same frequency and intensity. However, once the forest was removed (and at the beginning of zone B2 the secondary forest taxa are apparently replaced by Poaceae) fires may have become less frequent.

Climatic conditions in the delta region have probably shown little overall variation in the past 4000 years or so and since humid conditions have probably prevailed, the postulated dryland fires are unlikely to have resulted from natural causes. Anthropogenic disturbance is implied in the records of vegetation change from both Bonatoa and Raralevu.

Human impact in the region

The Bonatoa Bog pollen sequence is tentatively interpreted as indicating the presence of man in the Rewa Delta region from about 4000 BP. This pre-dates the earliest dated archaeological sites, but not by a substantial amount. It is certain that human occupation precedes the establishment of large settlement sites, such as those which yield the earliest dates in Fiji, by a considerable period of time.

The initial changes in the pollen spectra show the replacement of mixed rainforest by firstly secondary forest taxa and then by grasslands. The latter substantial change had taken place by 3000 BP and is perhaps indicative of more intensive human activity in the region. A comparison with the Raralevu data, however, suggests that this intensive activity was localised in the delta.

Intensification of human impact on the slopes was possibly matched by a similar degree of activity in the wetlands. *Metroxylon vitiense*, sago, was common in the Bonatoa pollen spectra until about 3000 BP, it then decreased and disappeared. This taxon was probably placed at an ecological disadvantage by autochthonous changes in the swamp, related to the onset of peat accumulation, but the decline in its pollen production might also reflect harvesting of the plant by man. Sago could have provided a staple food crop for the local population, perhaps while other agricultural resources were being developed. By about 1400 BP, however, with the development of a *Pandanus* swamp at the site, *Metroxylon* had disappeared. Whether it was deliberately cleared, perhaps to make way for other wetland activities, is unclear, although it seems unlikely that such a source of excellent roof thatch, if not food, would be disposed of.

The modern pollen samples from the Navua Delta suggest that *Metroxylon* pollen does not travel far and therefore its disappearance from the Bonatoa pollen spectra may simply reflect a movement away from the vicinity of the pollen core site. It is unlikely to have been growing on peat though, and it may have naturally retreated to the slope/swamp boundary where an accumulation of colluvium would have provided a suitable substrate (cf. its present distribution in the Navua Delta). The Raralevu pollen spectra suggest *Metroxylon* was growing nearby, but probably not on the swamp proper, until about 1000 BP. During the past 1000 years increased human activity has probably restricted its distribution even further and led to its virtual disappearance from the Rewa Delta region.

Intensified human activity is indicated in the Bonatoa pollen spectra from about 3000 BP; the Raralevu record which begins at 2000 BP suggests increased dryland burning from about 1000 BP. The basal Raralevu pollen spectra indicate that a mosaic of forest, secondary forest and grassland may have characterised the surrounding slopes, indicating prior disturbance. The tentative explanation given for the channels in the Raralevu peatlands also suggests an earlier phase of human activity, but the data suggest that if the site had been drained and utilised, it had been abandoned by 2000 BP.

The pattern emerging from the Rewa Delta is one of shifting centres of human activity, perhaps as a result of an increasing population, changing edaphic conditions as the delta built up, changing channel configurations as a result of periodic catastrophic floods, or a combination of these factors. The most intensive and extensive activity in the region has apparently occurred since about 1400 BP at Bonatoa and encompassed Raralevu from about 1000 BP. It is most likely that the population in the area became centralised into political units during this period and the fortified villages may well have developed as a result. The pollen and stratigraphic data, however, indicate that wetland management and dryland degradation had occurred from an earlier time.

6.3 The Regional Setting 2: Navua Delta

6.3.1 Physical Environment

The Navua Delta is located on the south coast of Viti Levu, about 40 km west of Suva (Figure 6.1). The Navua River drains a catchment of about 1060 km^2 in the Korobasabasaga Range and Mt Gordon Highlands and extends to the north as far as the edge of the Nadrau Plateau. These hills consist of the Miocene Serua volcanic conglomerate which overlies the Nubuonaboto conglomerate of the Wainimala Group. The latter outcrops to the north in the main part of the Mt Gordon Highlands (Band 1968).

Alluvial deposits in the delta cover approximately 47 km^2, overlying marine and estuarine material (Macdonald *et al.* 1969). Two large deposits of peat have accumulated in the backswamp areas at Vunimoli and Melimeli, which cover 461 and 507 ha, respectively, although prior to artificial drainage in the past 30 years or so, Vunimoli was much larger in area, as shown on Figure 6.8. In these areas the drainage is impeded by the levee banks of distributary channels to the west and east, and by beach ridges to the south of the delta, see Figure 6.8.

Climatic conditions in the Navua Delta are similar to those experienced in the Rewa Delta, but with slightly higher average annual rainfall totals. Rainfall data for the region are available from Naitonitoni at the coast, Navua, which is slightly inland, and Namosi Mission, for the years 1937 to 1955, in the upper reaches of the Navua catchment. These figures are presented in Table 6.4.

The hills behind the coastal plain effectively block rainbearing winds and orographic rainfall is common. Thus average annual rainfall increases away from the coast, ranging from 3073 mm per annum at Naitonitoni to 4192 mm at Namosi Mission. Despite high average annual totals, rainfall in the region is highly variable. Floods and short droughts are likely to occur in the Navua Delta in any month of the year. Major floods have a return period of approximately 1.1 years in

Figure 6-8: Major Features of the Navua Delta

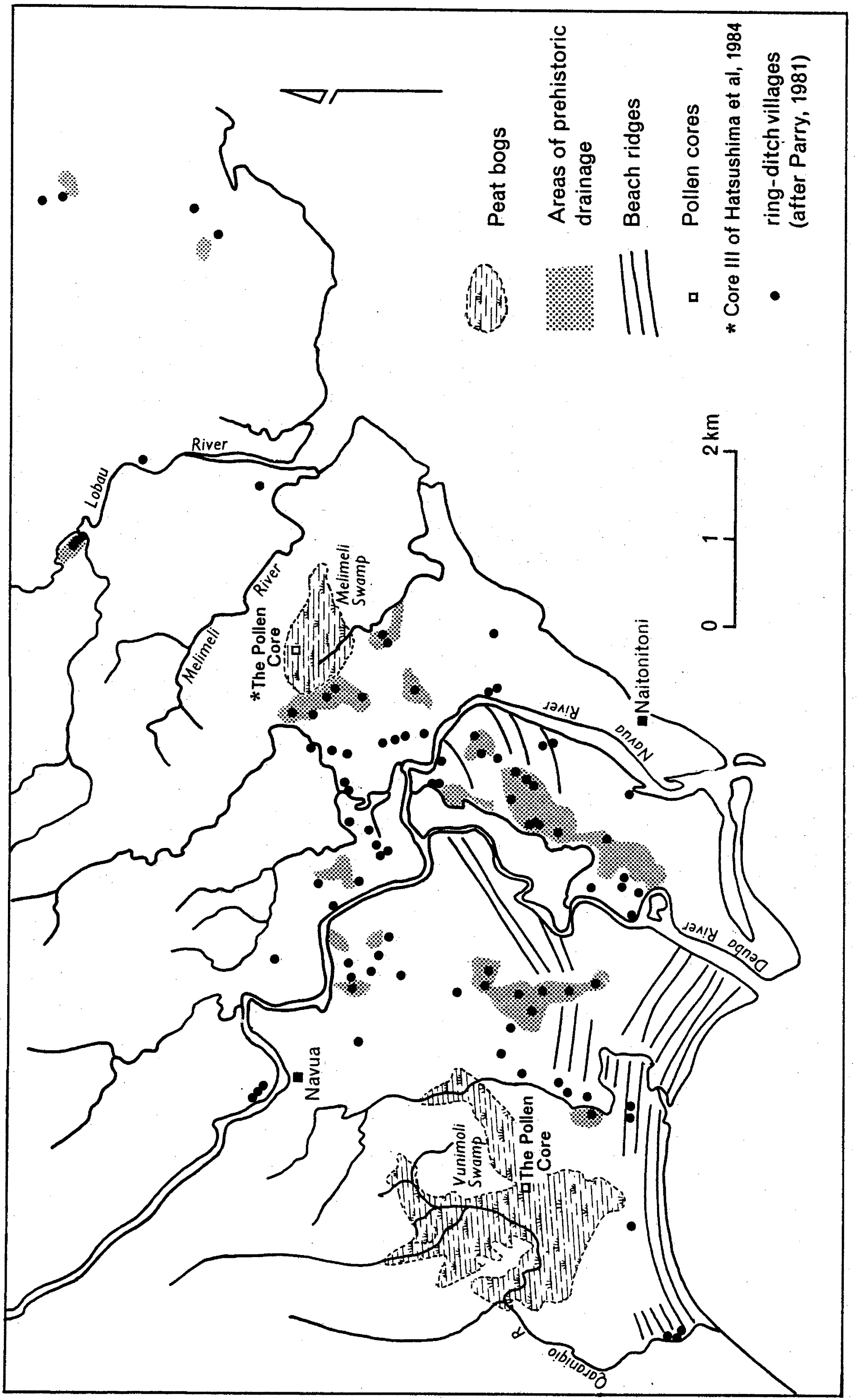


Table 6-4: Rainfall in the Navua Delta

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Ncitonitoni	317	303	365	349	266	171	155	184	199	211	273	280	3073
Navua	456	276	473	434	373	187	206	203	312	338	378	392	4028
Namosi Mission	472	518	645	489	283	184	188	147	245	285	340	508	4192

(data, in mm, from Fiji Meteorological Service 1980,
Macdonald *et al*. 1969)

the delta, while catastrophic floods are estimated to have a return period of 500 years (Macdonald *et al.* 1969).

Average annual temperatures in the Navua Delta are about 25.5°C (Fiji Meteorological Service 1980), which is similar to average sea surface temperatures for the region.

6.3.2 Vegetation

Large-scale clearance of the flat lands of the Navua Delta occurred during the 1880s for sugar plantations. Although climatic conditions and drainage problems eventually put a halt to sugar production and closed the Navua sugar mill in 1922 (Ward 1965), the delta has continued to be the focus of agricultural activity and only small pockets of the original vegetation cover remain.

At present the vegetation consists of several communities which are related to substrate conditions in the delta. At the base of slopes on water-logged colluvium, dense stands of the sago palm, *Metroxylon vitiense*, occur. Within the stands there are few other taxa, mainly epiphytes and ferns including *Ipomoea gracilis*, *Borreria laevis*, *Hyptis pectinata*, *Lygodium* sp., *Nephrolepis biserrata*, and *Stenochlaena palustris*. Sago swamps are at present uncommon in Fiji, occurring only in pockets along the south-east coast of Viti Levu, parts of Vanua Levu and Ovalau (Moore 1979). The stands of *M. vitiense* in the Navua Delta are probably the largest in Fiji.

Areas of peat support a similar assemblage of species as that found in the Rewa Delta. Introduced sedges are common, especially *Rhynchospora corymbosa*, *Fimbristylis dichotoma* and *Kyllinga polyphylla*. *Pandanus pyriformis* again occurs on deep peats, with an understorey of ferns and ground cover of *Sphagnum cuspidatum*. There is some merging of freshwater wetland and mangrove vegetation in the Navua Delta with a typical succession of dominant species from mangrove to freshwater conditions as follows: *Rhizophora samoensis* to *Lumnitzera littorea* and *Brugiera gymnorhiza* to *Pandanus pyriformis* and *P. whitmeanus* to *Acrostichum aureum* to *Sphaerostephanos unitus* to *Nephrolepis biserrata* to *Eleocharis dulcis* and *E. ochrostachys* (Ash and Ash 1984).

Extensive agricultural activity has not encroached substantially on the surrounding hillslopes, although selective logging has occurred since the 1920s. The remaining forest vegetation probably corresponds to forest type 1A1c, tropical evergreen ombrophilous montane forest, and has been enumerated by Berry and [AHoward (1973). The forest forms a closed canopy 25 m high, consisting of *Myristica castaneifolia*, *Parinari insularum*, *Endospermum macrophyllum*, *Palaquium hornei* and species of Myrtaceae and Sapotaceae. Prior to logging *Degeneria vitiensis*, *Trichospermum* spp., *Neonauclea forsteri*, *Premna taitensis*, *Sterculia vitiensis*, *Calophyllum vitiensis*, *Gonystylus punctatus*, *Dysoxylum richii* and *Canarium* spp. were probably also common.

6.3.3 Human Impact

Oral traditions of the Deuba people in the west of the delta suggest a group of their ancestors moved from inland perhaps 250 years ago and joined people already living in boats at the coast. Together they built permanent settlements on land (Geddes 1945). Recent archaeological excavations in the Navua Delta region have revealed pottery associated with fortified village sites which suggests an age of about 1500 BP, and this will be tested using ^{14}C dating (G. Irwin, personal communication).

The Navua Delta has a much lower concentration of prehistoric fortified village sites than the Rewa, and only about 25 to 30 were occupied at the time of european contact (Parry 1981), indicative of a small local population. It is likely that the impact of prehistoric man in the Navua region was less severe than in the more densely populated Rewa Delta.

6.4 The Pollen Sites 2: Navua Delta

Two sites were chosen for pollen analysis from the Navua Delta, at Vunimoli and Melimeli, the major areas of peat development in the delta region, and Vunimoli at least is located close to the sites of prehistoric villages and might reflect the impact of man. As with the Rewa Delta sites, it is likely that the origin of both Vunimoli and Melimeli is related to sea level changes. The site at Melimeli had been previously examined stratigraphically and ^{14}C dated for evidence of past sea levels in the Fiji region (Matsushima *et al.* 1984 - the site is referred to as Lobau in this publication). Since the stratigraphy, dating and pollen analysis of Vunimoli did not agree with the results of Matsushima *et al.* (1984), it was felt that further investigation was necessary at Melimeli.

6.4.1 Vunimoli

This site is located in the west of the Navua Delta (Figure 6.8). It is an area of peat which has accumulated because of impeded drainage due to the presence of beach ridges to the south and of levee banks of channels (e.g. the Qaraniqio River) to the east and west. Extensive drainage of the swamp has occurred and much of the original peatland has been destroyed in the process. Macdonald *et al.* (1969) reported up to 2 m of peat in the area, but the maximum depth of peat now seems to be about 1 m, perhaps because of shrinkage and deflation following drainage.

Swamp vegetation

Undisturbed and undrained areas towards the northern edge of Vunimoli and at the base of the hills support the *Metroxylon vitiense* swamp community described above. This gradually merges with vegetation dominated by *Pandanus pyriformis* on undrained areas of Vunimoli with introduced sedges and grasses, and the presence of *Sphagnum* is indicated only by sparse hummocks, currently drying out and disappearing. It is likely that in the past *P. pyriformis* with sedges, ferns and *Sphagnum cuspidatum* extended coastwards and merged with the mangrove vegetation. There was a small patch of *Lepironia articulata* within the swamp at Vunimoli, which had previously been recorded only from Lake Tagimaucia (Koyama 1979), but this was destroyed by further drainage and fire in 1984.

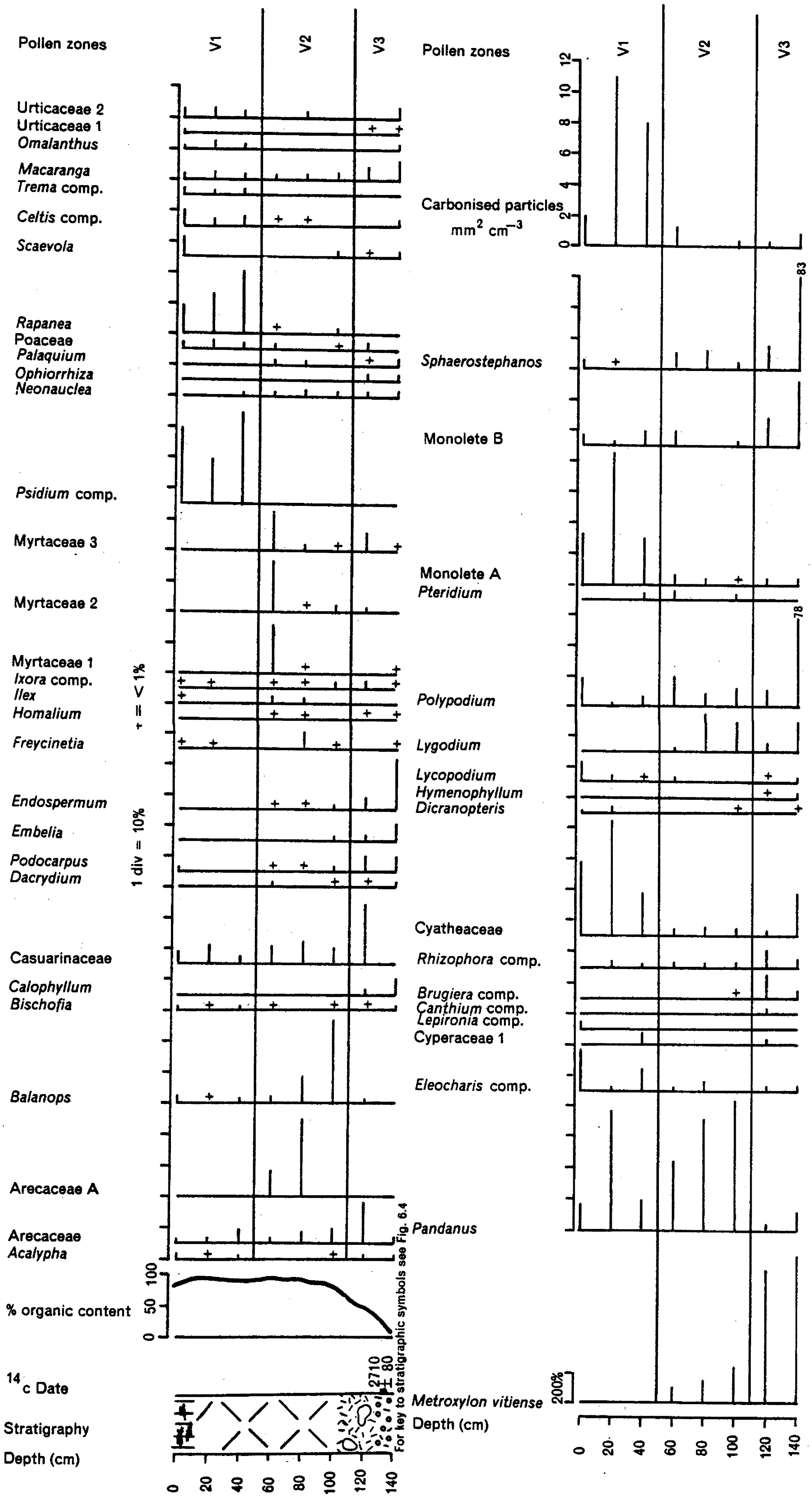
Stratigraphy of the site

During extension to the housing complex near Vunimoli, a further drainage channel was excavated into the remaining area of peat. The stratigraphic profile which was revealed consisted of a dried surface layer of roots of living plants to 10 cm in depth, merging with underlying highly organic peat (see Figure 6.8 for location and Figure 6.9 for a diagrammatic representation).

The peat is increasingly humified with depth and at about 140 to 150 cm below the surface, it merges with the underlying sands. The excavation also revealed a layer of tree stumps apparently *in situ* at the base of the peat within what appeared to be a thin soil horizon. A pollen site was chosen in one of the deeper peat areas.

The site was surveyed using an automatic level to establish the relationship of the peat deposit with present mean sea level. A bench mark on the old Queen's Road, south of Vunimoli was used as the datum point for the survey and heights were later adjusted to metres above msl. The surface of the peat at Vunimoli varied from 2.82 to 4.04 m above msl. At the pollen site, the surface of the peat was 3.89 m above msl. The altitude of the sand layer which underlies the peat

Figure 6-9: Vunimoli Swamp: Percentage Pollen Diagram



was also surveyed where it was exposed in the drainage channel. It varied from 2.61 to 3.61 m above msl across Vunimoli, suggesting a series of small ridges and crests similar to those visible at the surface further south in the delta. At the pollen site the sand/peat boundary was 2.63 m above msl.

Driftwood was revealed *in situ* at the sand/peat boundary downstream from the pollen site in the excavated channel. It was felt that a ^{14}C date from this wood, coupled with its altitude above present mean sea level might indicate the location of past sea levels. A sample of the wood was submitted for ^{14}C assay which gave a reported date of 4360+/-120 BP (ANU-3809). Levelling to the driftwood site suggested the sample was deposited at 1.7 to 1.8 m above present msl, which is only .6 to .7 m above the highest astronomical tide (Anon 1984). Since driftwood occurs on modern beaches up to 2 m above msl, especially after cyclonic events, there is no reason to assume the presence of driftwood beneath the Vunimoli peats indicates a higher sea level. The information suggests rather that sea level has probably been at its present level for at least the last 4000 years. The coastline, however, has obviously been prograding during this time, ultimately cutting the Vunimoli area off from the sea, impeding drainage and allowing for the development of peat deposits.

The pollen diagram

Material for pollen analysis was collected as a monolith in 50 cm sections from the cleaned face of the drainage channel. These sections were wrapped and sealed in plastic, labelled and taken to the laboratory for analysis. Samples for pollen analysis were extracted from the centre of the monolith at 20 cm vertical intervals and prepared using the standard technique described above. Extra material from the same levels was analysed for organic content. Pollen counts proceeded on the prepared pollen slides until at least 200 grains had been recorded, and this formed the pollen sum. *Metroxylon vitiense* and pteridophytes were excluded from this 200 grains since both were often over-represented and would have distorted the percentages of the other pollen taxa. Carbonised particle concentrations ($mm^2\ cm^{-3}$) were also estimated from the pollen preparations using the point count method, and a relative error of 25%.

Material for ^{14}C dating was extracted from 133 to 135 cm which marked the boundary between sand and peat in the stratigraphic profile. The sample yielded a reported ^{14}C age of 2710+/-80 BP (ANU-3808).

The pollen assemblages, stratigraphy, organic determinations and ^{14}C date are presented on Figure 6.9. The stratigraphic section is characterised as follows.

0 - 20 cm	The surface material is blackened, probably by burning, and the material is compressed. Pellets of organic material have formed suggesting a lengthy period of surface drying. Organic content is high (ca. 85%).
20 - 130 cm	Light brown fibrous sedge peats occur at these depths with some wood inclusions. There is a much darker organic horizon at 55 to 70 cm. Organic content is correspondingly high (ca. 95%).
130 - 150 cm	At the base of the peat there is an abrupt change to an organic soil horizon, with *in situ* tree stumps. Organic content falls dramatically at these depths to <40%.
150+ cm	There is another abrupt boundary between the soil horizon and the underlying sands. These are extremely inorganic, grading from yellow/green to grey with depth, and are probably marine in origin.

Zonation of the pollen diagram

The Vunimoli pollen diagram has been divided into three local zones which are described below.

Zone V3 140 - 120 cm

This zone is characterised by very high values for *Metroxylon* (>800% of the pollen sum). There are low values for *Pandanus* and the mangrove taxa *Rhizophora* and *Brugiera* comp. Dryland taxa are best represented by Arecaceae, Casuarinaceae (probably *Gymnostoma*), *Calophyllum*, *Podocarpus*, *Endospermum* and *Macaranga*. The pteridophytes are dominated by *Polypodium* comp. and *Sphaerostephanos* comp.

Zone V2 100 - 60 cm

Metroxylon declines towards the top of this zone. *Pandanus*, on the other hand, becomes quite common and dominates the swamp pollen spectra. The mangrove taxa become less common. Most dryland taxa which were common in the basal samples, decline in importance, although dramatic increases are demonstrated by *Balanops*. The pteridophytes are best represented by *Lycopodium*, but most taxa are uncommon in this zone.

Zone V1 40 - 0 cm

The upper zone is characterised by the disappearance of *Metroxylon* from the pollen record and an increase in *Eleocharis* comp. There is a marked increase in the representation of *Psidium* comp. and *Rapanea*, while *Celtis* comp., *Trema* comp., *Omalanthus* and Urticaceae 2 are more consistently represented. The pteridophytes are best represented by Cyatheaceae and Monolete A. Carbonised particles are abundant in this zone.

Discussion

The wetland vegetation at the beginning of this record was almost certainly *Metroxylon* swamp, similar to that which exists in the area at present, although values are higher than any recovered in modern pollen samples. It is possible that the local production of *Metroxylon* pollen was augmented by pollen washed in from upstream in the delta area. Much of the Vunimoli area of the Navua Delta was probably covered in sago swamp at this time and was likely to be largely influenced by freshwater inundation. The small quantities of mangrove pollen in the basal levels, similar to that recorded in surface samples across the site at present, suggest the presence of mangrove swamp nearby, but probably not occurring as part of the Vunimoli Swamp vegetation. These data strongly indicate that the beach ridges seaward of Vunimoli were in place. If the accumulation of peat is an indication of impeded freshwater drainage, then the date of 4360 BP for driftwood lying at the sand/peat boundary on the seaward side of the pollen site suggests that the ridges were probably constructed by this time.

The tree stumps present in the organic soil at the base of the Vunimoli core are enigmatic. While the pollen spectra strongly indicate the presence of sago swamp at Vunimoli at this time, the *in situ* stumps are obviously not the remains of *Metroxylon vitiense*, but rather species of hardwood trees, although a positive identification could not be made. It is possible that prior to the build up of the seaward beach ridges, beach forest developed inland in the Vunimoli area on older sand deposits following minor soil development. When the seaward beach ridges formed, freshwater drainage through the area was probably impeded, effectively destroying the conditions which allowed development of beach forests. On the other hand, conditions subsequent to impedence of freshwater drainage probably favoured the invasion of sago swamp in the area. Continued availability of ponded freshwater would then have allowed the invasion of peat forming taxa and later the exclusion of *Metroxylon* as peat accumulation occurred. The gradually declining values for *Metroxylon* may suggest that this taxon moved progressively further inland as the area of peat expanded.

The vegetation contributing to the peat formation was probably the *Pandanus*-sedge community common to most coastal swamps in Fiji at present. The pollen spectra suggest this community has occupied much of the Vunimoli site from about 2300 BP to the present.

Fluctuations in the dryland pollen taxa at the zone V3/V2 boundary suggest changes in the forest vegetation, from dominance by *Calophyllum*, *Podocarpus*, *Endospermum*, and *Embelia*, to dominance by *Balanops* initially; then Myrtaceae, *Celtis* comp., *Trema* comp. and *Rapanea*. The taxa in zone V3 are common in subcoastal rainforests at present, but the mix of taxa which replaced this assemblage is uncommon. *Balanops* is an enigmatic taxon in Fiji. It occurs at all elevations and probably has little interpretative value in pollen diagrams. The taxa which apparently replace *Balanops* may suggest some form of forest disturbance took place such that the secondary forest taxa, *Celtis* and *Trema* became common. The high values for Myrtaceae may represent movement of such taxa onto the swamp itself.

At present the guava, *Psidium guajava*, is common in the swamp vegetation, and much of the Myrtaceae pollen bears a strong resemblance to *Psidium*. Since it is associated with human disturbance at the present, there is the strong suggestion that its appearance in the fossil assemblages is indicative of human disturbance in the area.

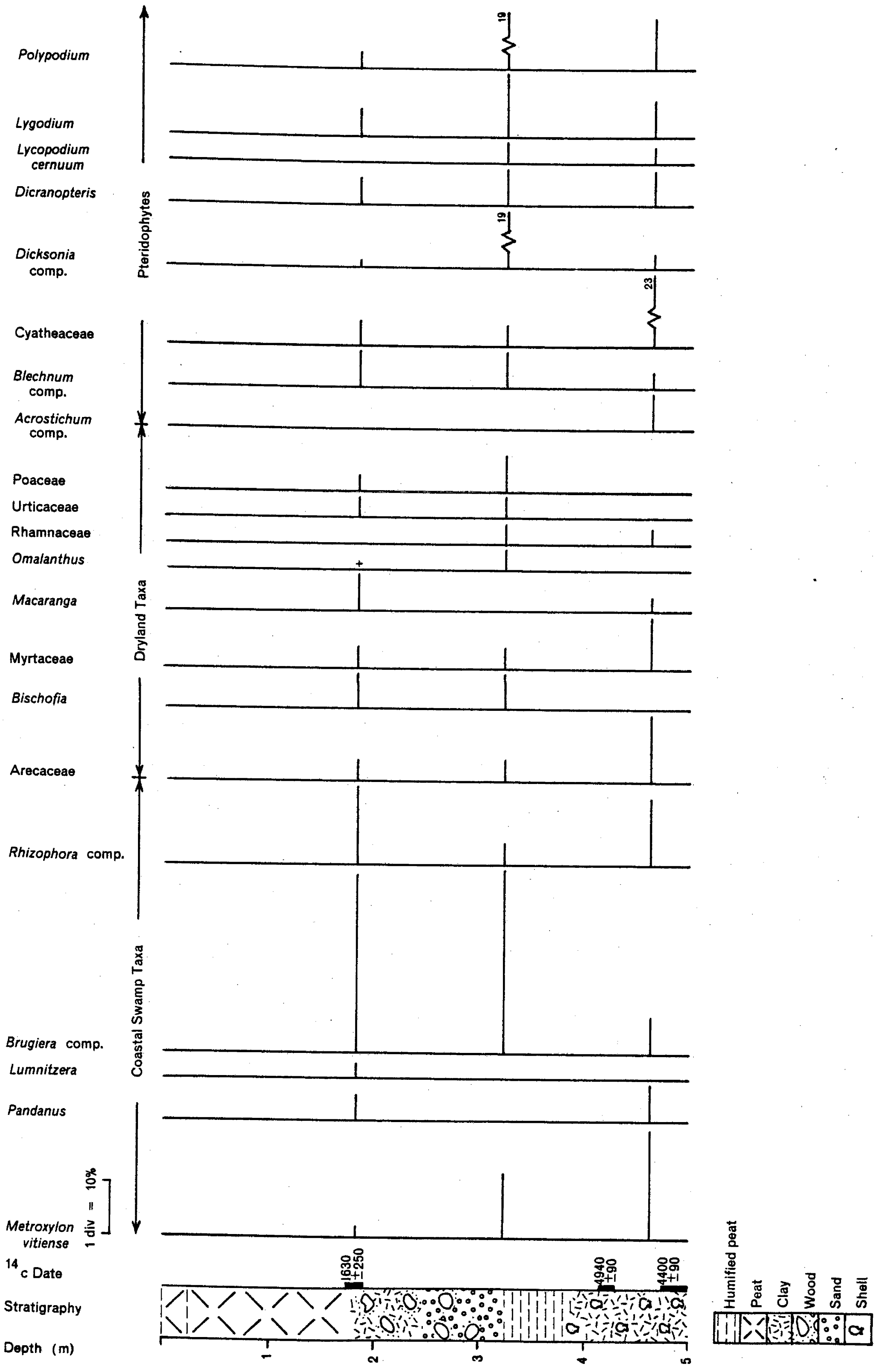
6.4.2 Melimeli

The Melimeli peatlands are located in the east of the Navua Delta, see Figure 6.8. They have developed in an area of impeded drainage behind beach ridges and levees of the distributary channels of the Navua River, overlying fine textured alluvium to the north and west and coarser coastal deposits to the south-east (Macdonald *et al.* 1969). The beach ridges do not form as complete a barrier in this part of the delta as they do to the west near Vunimoli. There is a maximum of about 2 m of peat in the inland part of the swamp which shallows towards the margins. The remaining natural vegetation at Melimeli is similar to that at Vunimoli, although extensive drainage has occurred to render the area suitable for pastoral and agricultural activities.

Matsushima *et al.* (1984) cored through the organic deposits in two places at Melimeli (see Figure 6.8) in an attempt to determine Holocene sea levels in the area. The core sites were surveyed and the cores were described stratigraphically, ^{14}C dated, and the diatom flora analysed. From these data, Matsushima *et al.* proposed a tentative sea level curve which showed that the sea level rose rapidly from between about -1.5 m and -1.75 m about 4400 years ago, and reached about 1.6 m above the present sea level about 3000 to 2000 years ago. This sea level curve is in obvious disagreement with the results from the Rewa Delta and Vunimoli, which suggest that sea level was most likely at its present level by 4300 BP and has not risen significantly since then. As a result of these observations the Melimeli sites were relocated, resurveyed and cored (Ash and Ash 1985). It was found that the surface level of the longest core was probably in error by +1.12 m and therefore the proposed high sea level (which was based on the presence of a marine diatom flora to 1.9 m in depth in the original core) was most probably also in error. Given the adjusted surface levels, the upper limit of the marine diatom flora is within the present tidal range and does not require a higher sea level than present. A modified sea level curve was presented by Maeda *et al.* (1986).

A few pollen samples were prepared from the Melimeli site to substantiate the interpretations of sea level movement. Counts proceeded to 150 grains where possible, but pollen concentrations were generally low and only small pollen counts resulted, these are presented on Figure 6.10.

Figure 6-10: Pollen Samples from Melimeli Swamp



The pollen diagram

The samples for pollen analysis were collected from a D-section core extracted near site III of Matsushima *et al.* (1984); its stratigraphy is redrawn from Ash and Ash (1985) and the ^{14}C dates are derived from Sugimura *et al.* (1983) and Matsushima *et al.* (1984). There was a close correlation in the stratigraphy of both cores and it was assumed the ^{14}C dates could be used to provide a tentative chronology. Although there is a reversal in the two basal dates, the later date of 4400 BP, which is from *in situ* shell, probably records the onset of sedimentation. It is suspected that the older sample of coral which gave the result of 4940 BP may have been transported to the site.

The stratigraphic section is characterised as follows.

0 - 25 cm	The surface layer consists of slightly humified peat with some silt, probably colluvium from the nearby slopes.
25 - 180 cm	This is a layer of fresh peat with many macrofossil plant inclusions.
180 - 300 cm	The peat becomes humified with depth and is mixed with sand and wood fragments.
300 - 380 cm	The wood and sand inclusions disappear at these depths and a layer of slightly organic sand and silt remain.
380 - 500 cm	The basal sediments in this core are a mixture of sand, silt and shell fragments with some *in situ* shell (*Chama pacifica* and *Saccostrea mordax*) at the base.

The pollen samples which were examined showed most changes in the coastal swamp taxa. The spectra record the apparent decline of *Metroxylon vitiense*, while *Brugiera* comp. shows an overall increase towards the surface. Most of the dryland forest taxa are consistently represented throughout the samples.

Discussion

The stratigraphy of this core is rather different from others recovered from coastal sites in Fiji in that it contains abundant shell material at the base. However, this material was deposited approximately 2.5 m below present msl, in contrast to the other coastal cores whose basal material is more or less at mean sea level. This may be largely because the beach ridges which isolated the Vunimoli site from the sea form a less continuous barrier near Melimeli. It is likely that a marine succession occurred at Melimeli, with largely inorganic sediments building up to the height of mean sea level and then organic sedimentation occurring as freshwater conditions prevailed.

The pollen spectra suggest that *Metroxylon* swamp may have persisted nearby from about 4400 BP, diminishing in importance to about 1600 BP. The *Metroxylon* was probably migrating towards the rear of the delta as progradation occurred. It is interesting that the mangrove taxa are more common in the upper two samples, when mangrove communities were presumably more extensive during the earlier phase of sedimentation. The shelly facies at the base may indicate that conditions were unsuitable for mangrove vegetation in the immediate vicinity of the pollen site and that the pollen which is present was washed in. Pollen concentrations are extremely low in these sediments which substantiates the claim for no *in situ* vegetation. The higher representation of mangrove taxa in the upper samples may be an artifact of better conditions for pollen preservation, although the data do suggest the presence of mangroves nearby. Notably *Brugiera* is most common and this forms the inland zone of the mangrove fringe. This is consistent with the present distribution of vegetation types in this part of the delta. *Metroxylon* disappeared from the vicinity of Melimeli sometime between 1600 BP and the present. This echoes the pattern displayed in the Rewa Delta records.

Representation of dryland taxa is limited, but most taxa maintain similar values in all samples. It is difficult to determine the vegetation type the pollen spectra represent, but it is probably similar to the present forests near Melimeli. There is little indication of major disruption of the forest cover.

6.5 The Nature of Environmental Change in the Delta Regions

6.5.1 Sea Levels and Coastal Wetland Vegetation Development

The Rewa and Navua data concur on the likelihood that present sea level was reached along the southern coast of Viti Levu by about 4300 BP. There is no evidence to suggest that sea levels higher than the present have occurred since that time. While the reinterpretation of the Melimeli data suggested present sea level was reached at about 1600 BP (Ash and Ash 1985), this was a minumum date and the event may have occurred at an earlier time.

Substantial series' of beach ridges were formed as sea level rose and these have effectively minimised marine influences in these two delta regions. Extensive alluvial and peat deposits have accumulated in the past 4000 years or so, giving rise to some of the most fertile and easily cultivatable lands in the country. It is for this reason that these areas were the focus of intensive human activity in the past, and are still utilised at present.

Extensive areas of mangrove vegetation probably occupied both the Rewa and Navua Deltas prior to the construction of beach ridges. There is some indication of such estuarine facies in the Melimeli stratigraphy, but this area was not so completely isolated from marine influences, because the beach ridges do not extend continuously as far east in the Navua Delta.

Once freshwater drainage was impeded, *Metroxylon vitiense* swamp appears to have become established in both deltas. This taxon had a much more extensive distribution in the past and it may have occupied most of the delta flats in windward Fiji when present sea level was first reached. Subsequent developments in the deltas, which are related to autochthonous changes as the deltas built upwards and outwards, and perhaps anthropogenic disturbance, ultimately caused a reduction in the *Metroxylon* communities.

The *Metroxylon* may have retreated landwards as organic sediments began to accumulate and finally assumed its present distribution at the swamp/slope boundary, where colluvium forms the substrate. In the Navua Delta, especially near Vunimoli, the sago communities have survived in these locations. However, in the Rewa Delta the pollen data suggest that while *Metroxylon* may well have grown at the swamp margins until at least 1000 BP, it has since virtually disappeared. Suitable habitats exist to support *Metroxylon* swamp and it seems likely the anthropogenic disturbance throughout the delta region may have contributed to its demise.

The major development of peatlands apparently dates from the decline in importance of *Metroxylon*, which varies throughout the sites from 2300 BP at Vunimoli, to 1600 BP at Melimeli, to 1400 BP at Bonatoa Bog, and to 1000 BP at Raralevu. The *Pandanus* swamps, which are the most common coastal wetland communities at present, apparently developed from this time. If sea level had been higher than present at about this time, as Sugimura *et al.* (1983) suggest, then it seems likely that neither *Metroxylon* nor *Pandanus* swamps would have developed in the delta regions until much later. The vegetation data substantiate the stratigraphic interpretation of no significant sea level change since about 4300 BP.

6.5.2 Development of the Coastal Dryland Vegetation

The earliest pollen record for dryland vegetation in the delta regions comes from Bonatoa Bog. At about 4300 BP, the pollen spectra imply a mixed forest which closely resembles the present day subcoastal forest, enumerated by Berry and Howard (1973). The limited data from Melimeli support this interpretation. The presence of such forests implies that climatic conditions were also likely to be very similar to the present.

By about 3000 BP the dryland forest vegetation near Bonatoa was replaced by secondary forest taxa and then by extensive grasslands. The data from Raralevu suggest that by 2000 BP a mosaic of forest, secondary forest, and grassland extended throughout large parts of the Rewa Delta.

In the Navua Delta, the Vunimoli pollen sequence indicates that the dryland vegetation was very similar to the earliest Rewa Delta forests, until about 2300 BP. At this time the pollen spectra suggest the dryland vegetation became dominated firstly by *Balanops* and then by Myrtaceae and *Rapanea*. There is no indication that a mosaic of vegetation types existed in the Navua Delta from this time, although there was a replacement of forest types.

It was suggested above that the changes in dryland vegetation in the Rewa Delta were probably a result of human activities, such as burning and clearing, and this will be discussed further in the following section. At Navua the evidence for human activity is far less clear. This southern part of the Viti Levu coast receives higher rainfall than the Rewa area and it is possible that dryland habitats converted less readily to grassland when disturbed, although the forest composition changed. A lower population density in the area may have caused less substantial disturbance in dryland habitats. At present large areas of the Navua catchment forests show little sign of disturbance.

6.5.3 Human Impact in the Delta Regions

As was noted at the beginning of this chapter the dense clusters of fortified villages and extensive areas with reticulated drainage, presumably for wetland cultivation, indicate a fairly intensive human effort and a large population in the delta regions in prehistoric times. The pollen sequences from the Rewa and Navua Deltas indicate that human impact may extend back 4000 years or so and that there has been a range of agricultural activities over space and time during that period.

The evidence for settlement on Viti Levu by about 4000 BP is not concrete. It was argued above that the composition of the dryland vegetation suggested that climatic conditions were similar to the present at 4300 BP and therefore natural fires would be uncommon. Thus, human intervention seems the most likely explanation for the catchment fires which are indicated by this time in the Rewa Delta. The forest composition gradually changed to a mixture of primary and secondary forest taxa until 3000 BP, when grassland is apparent in the catchment. This suggests a gradually increasing human impact on the dryland environment. Sediment loads in the Rewa system may have increased from this time and caused the formation of levees and extension of the delta flats.

Metroxylon swamp was extensive in the Bonatoa area from 4300 BP and its pollen declines in importance from 3000 BP, eventually disappearing from the record at about 1400 BP. It was suggested above that there may have been one of two reasons for its demise, or a combination of both. Firstly, developments in the delta may have placed *Metroxylon* at an ecological disadvantage and caused it to migrate towards the valley sides where more suitable substrates prevailed. Alternatively, the swamps may have provided a staple food crop, the harvesting of which would reduce the amount of pollen produced. *Metroxylon* probably retreated completely from Bonatoa by 1400 BP when a peat-forming *Pandanus* swamp was established, so it is likely that its disappearance may be attributed to both factors.

There is thus some evidence to suggest that human activity intensified in the Rewa Delta at about 3000 BP. The Raralevu site dates from about 2000 BP and the evidence of the channels strongly suggests that the area had witnessed agricultural activity prior to this time. Natural channel shifting in response to major flood events which altered the hydrology of the area may have caused its abandonment. The mosaic of forest, secondary taxa and grasslands on dryland suggests either that anthropogenic disturbance on dryland was less significant, or that there had been some recovery of the vegetation since initial clearance. The evidence suggests that both dryland and wetland habitats were simultaneously abandoned near Raralevu.

The Rewa Delta vegetation histories indicate increasing intensification of human activity in the area. They also suggest that the focus of activity probably shifted in the delta throughout its history. Given the dynamic nature of a delta system, even without anthropogenic disturbance, this is not surprising.

In the Navua Delta there are less obvious indications of human impact in the vegetation record, despite the surface evidence for extensive prehistoric activities. This tends to substantiate the claim that population densities were lower in this area, compared to the Rewa Delta (Parry 1981). The wetter conditions may have made the area less attractive for settlement and the initial movement into the area probably occurred later than further to the east and west. There is a suggested time-depth of 1500 years to the fortifications in the Navua Delta. It is perhaps coincidental that the period of most intensive activity in the Rewa Delta dates from about 1400 BP, but it may suggest that this period was marked by increasing population pressures on the delta lands and the centralisation of people into defensible village units.

Archaeological evidence for the early occupation of the Rewa Delta is probably buried beneath the sediments which have accumulated in the past 4000 years or so. Sites on the surrounding slopes may exist, but heavy vegetation cover and perhaps 4000 years of increasing human activity precludes their discovery. Kirch (1975) has noted that the earliest agricultural sites in these environments would be restricted in area and that a minimum amount of environmental alteration would be expected, given the small colonising populations.

CHAPTER 7

DISCUSSION: LATE QUATERNARY ENVIRONMENTAL CHANGE IN FIJI

The palynological evidence presented in the preceeding chapters provides a broad framework for assessment of environmental change in Fiji during the late Quaternary. Several aspects of environmental change were evident in the vegetation histories, and several scales of environmental variation were noted, as follows:

1. long term climatic variation effecting broad scale vegetation changes;
2. long term sea level change which in this study is related to the waning of the last glaciation and influences both broad scale dryland vegetation change and more localised coastal vegetation change;
3. shorter term environmental perturbations including minor tectonic activity and more significant volcanic events, the effects of which are often limited in area;
4. the impact of humans on pristine island environments during the late Holocene; the impact is often localised but also severe.

These points provide the basis for discussion in this chapter.

7.1 Vegetation and Climatic Change in Fiji

The pollen sequences from Wainisavulevu Creek and Lake Tagimaucia yield information on long term vegetation change in Fiji. The record from Wainisavulevu Creek is brief, but it relates to the vegetation of the central Nadrau Plateau at about 23 000 BP - the period immediately preceeding the last glaciation. The Tagimaucia record begins at 14 300 BP and continues to the present, giving a history of the vegetation of central Taveuni. These records may be linked to provide a general picture of late Quaternary vegetation and climates in windward Fiji.

The present vegetation of the wettest upland parts of Fiji (i.e. the Wainisavulevu and Tagimaucia areas) is tropical evergreen ombrophilous cloud forest, dominated by Myrtaceae, *Calophyllum* and *Ficus*, with some gymnosperm emergents. On the higher ridge tops where cloud cover is virtually continuous, the gymnosperms are generally absent, and taxa such as *Ascarina*, *Coprosma*, *Paphia*, *Freycinetia* and Cunoniaceae prevail (Smith 1981, 1985). Stunting of the vegetation is common and this is probably related to low temperatures and low transpiration rates under sustained cloud cover (Ash in prep. a). Gymnosperm taxa are most common in those areas of Fiji which receive a more seasonal distribution of rainfall (Smith 1979).

At 23 000 BP the pollen spectra from Wainisavulevu Creek suggest the vegetation nearby was dominated not only by the gymnosperm taxa, *Podocarpus* and *Dacrydium*, but with the ridge top elements as well. This combination of taxa is not presently found in Fiji, although analogues might be represented in the New Zealand vegetation (Godley 1975). The dominance of the gymnosperms is suggestive of more seasonal rainfall conditions than presently prevail on the Nadrau Plateau, and the suite of cool-adapted angiosperm taxa also imply some temperature reduction. In New Zealand, similar forests presently occur in areas with high rainfall (1600 to >3200 mm), cool temperatures and low evaporation (Coulter 1975; McGlone and Moar 1977). Such environmental conditions in Fiji would be consistent with a lowering of the cloud base in the Fiji region, so that taxa adapted to these conditions (e.g. those which presently occur on the highest ridge tops) expanded downslope and occupied much larger areas.

AT 14 300 BP the pollen spectra from Lake Tagimaucia suggest the vegetation in central Taveuni was dominated by gymnosperms (mainly *Podocarpus*, but with *Dacrydium*, *Dacrycarpus* and *Agathis*) with abundant *Ascarina*, but the ridge top elements common in the Wainisavulevu sequence are absent from the Tagimaucia samples until about 13 000 BP. It was argued in Chapter 4, by analogy with the present distribution of the gymnosperm forests, that this suggests very much drier and more seasonally arid conditions prevailed from at least 14 300 BP (and probably earlier) until 13 000 BP in central Taveuni. Because cloudiness may have been intermittent during a period when precipitation was at its minimum, the ridge and mountain top taxa which are representative of the coolest, and also cloudiest, conditions at present in Fiji are not recorded in the Tagimaucia samples. It is also possible that the pollen site was well above the cloud base at the height of the last glaciation.

Webster and Streten (1978) have suggested that at the height of the last glaciation, an enlarged area of sea ice surrounding Antarctica would have enhanced the latitudinal temperature gradient and caused both an equatorward shift in the westerlies and an incursion of cold mid-latitude water into the tropics. If this was the case, it may help explain the climatic changes implied by the Fijian vegetation histories. Lower sea surface temperatures in tropical waters would have resulted and thus reduced the available heat and moisture resources to promote cyclone genesis and maintain the smaller tropical disturbances which provide much of the wet season rainfall in the Fijian region. Generally cooler sea surface temperatures in the region would have reduced the moisture carrying capacity of the south-east trade winds. It is also likely that during the glacial period there was a weaker Southern Oscillation, which would result in less persistent south-east trade winds (Salinger 1981), thus further reducing the available precipitation. Such changes in the climatic patterns suggests that not only was precipitation reduced in the Fijian region, but it would have had a more seasonal distribution as the vegetation patterns imply.

The prediction of only 2°C of sea surface temperature reduction in the Fijian region at the glacial maximum by CLIMAP (1976; 1981) is probably not sufficient to account for the amount of temperature and precipitation reduction envisaged for Taveuni. The south-east trade winds and the wet season tropical disturbances must have contributed far less in the way of both orographic and convective rainfall to reduce the total rainfall to windward Fiji during the glacial period. It would seem that substantially lower sea surface temperatures are required both to the south-east and north of Fiji. The degree of temperature reduction implied seems much closer to the estimates of Quinn (1971), Aharon (1983), and Rind and Peteet (1985).

From 13 000 to about 9000 BP the vegetation in central Taveuni was probably very similar to that prevailing near Wainisavulevu Creek at 23 000 BP. The change in vegetation from the preceeding period suggests ameliorating climatic conditions, but for this particular suite of taxa (e.g. *Ascarina*, Cunoniaceae, *Coprosma*, and *Quintinia*) to have occurred at the elevation of Tagimaucia, temperatures were probably still at least 2°C below present averages at the beginning of the period. Increased cloud cover over Tagimaucia is implied, and given the fact that temperatures were probably still below present means, the cloud base was probably also maintained at a lower elevation than present.

The similarity between the Wainisavulevu Creek pollen spectra at 23 000 BP and those from Tagimaucia between 13 000 and 9000 BP implies that during the last glacial period (including the preceeding cooling and subsequent amelioration) the vegetation throughout windward Fiji may have been similar; that is, widespread gymnosperm forests with an understorey of angiosperm taxa. The pollen representation of ombrophilous cloud forest taxa was low in the Wainisavulevu and early Tagimaucia pollen spectra, but the fact that they were consistently present suggests this forest type was probably restricted to sheltered sites at lower elevations during this period of most extreme conditions.

The most likely mechanism in the Fijian region for this apparent amelioration would be an increase in the sea surface temperatures of the surrounding ocean. Warmer waters surrounding the islands would have resulted in more available moisture for transport by wind, resulting in increased cloud cover, orographic rainfall, major and minor tropical summer storm activity, and a stronger Southern Oscillation with persistent south-east trade winds (Salinger 1981). However, full climatic amelioration to present averages, including a rise in the cloud base to its present elevation, does not appear to have occurred until 9000 BP and the vegetation probably did not assume its present composition until about 6300 BP.

The apparently delayed response of the vegetation to ameliorating climate may have been largely due to sustained tectonic activity in the area, which would contribute to instability in the vegetation. It seems likely that the delay is not due to the time taken for taxa to invade the catchment vegetation, since distances are small in Fiji.

From about 6300 BP until the present the vegetation history recorded in the Tagimaucia pollen sequence, and the other Fijian pollen sequences which cover this period, suggest little or no climatic variation has occurred. The major vegetation changes which are evident may be related to sea level changes, tectonic and volcanic activity, and anthropogenic disturbance.

The environmental history of windward Fiji may shed some light on the likely environmental conditions in the past in leeward Fiji. If the summer rainfall input to Fiji was substantially reduced during the last glacial maximum, then periods of intense aridity probably affected many of the smaller low islands which do not generate orographic rainfall, and the north-western parts of the main islands, all of which receive most of their annual rainfall from summer tropical disturbances originating to the north-west of Fiji. Such a rainfall reduction would have resulted in average rainfall totals of less than 1000 mm per annum in some parts of leeward Fiji. The resultant vegetation patterns may have included extensive grasslands. Forest vegetation may have persisted in the sheltered upland areas of leeward Fiji, for example, the Nausori Highlands, and the separate development of the western and eastern forests of Viti Levu suggested by Smith (1979) may date from this time.

While natural grasslands may have prevailed under the harsher environmental conditions of the last glaciation, it would seem likely that in the period of climatic amelioration (to ca. 9000 BP), increasing rainfall would have resulted in the establishment of wooded communities, even in the driest areas. Exceptions to this might be the geologically older areas of Fiji in south-western and western Viti Levu which have inherently poorer soils. Grasslands may have persisted in these areas, and where woody vegetation did become established, the understorey may have consisted of grasses and ferns. Perhaps together these were the precursors to the *talasiga* formations of the present.

It was noted above that few of the fossil pollen spectra in the Wainisavulevu and Tagimaucia diagrams have modern analogues in Fiji. Hope (1986) has noted that vegetation communities can become extinct many times and that "the component taxa occupy subordinate niches in other communities, and can re-form the community when an appropriate niche appears which favours their competitive abilities" (Hope 1986 p 133). In an oceanic island ecosystem such as Fiji there is a limited number of environments available at any one time and as a result, when environmental conditions fluctuate (e.g. climate and tectonic activity), the number of former habitats diminishes, while new habitats are formed. On a time scale of thousands of years (i.e. the last glacial/interglacial cycle) the vegetation occupying the newly established habitats must derive from the stock already available. Thus a given community habitat need not be continuous in time if the component taxa can survive intervening periods in other communities (Hope 1986).

The synthesis of the subalpine forests of New Guinea in post-glacial times is suggested to have followed a similar course (Walker and Hope 1982; Hope 1986). The variety in these forest types reflects the isolation of the different mountain areas and the different species which were available to expand into areas made available by ameliorating climatic conditions.

Hope (1986) has suggested that the New Guinea Highlands communities are periodically re-created as changing conditions permit. This is also demonstrated by the Fijian data and since distances are small, migration time need not unduly affect the vegetational expression of changed environmental conditions.

7.2 Sea Level Change and the Fijian Environmental Record

There is little doubt that the most dramatic change throughout the islands of the south-west Pacific during the last glacial/interglacial cycle was the massive fall and rise in sea level. Islands disappeared as sea level rose, while the extent of the remaining islands was diminished. The effects of rising sea levels on the island ecosystems included changed drainage conditions and altered patterns of erosion and sedimentation as new base levels were reached. However, because the islands have narrow and steeply shelving margins, the impact of an extended continental shelf and its subsequent submergence on both climate and vegetation was minimal. This is in contrast to the situation in Australia and New Guinea where massive extension of the continental area occurred at the height of the last glaciation, affecting climates in certain regions.

At the sea level minimum (-140 m; Chappell 1982) Viti Levu was joined with the Yasawas, and Vanua Levu was enlarged to the edge of the sea reef, 50 km to the north, and was separated from Taveuni by a very narrow channel. Inter-island distances were much reduced. As sea level rose, the presently large deltas of south-eastern Viti Levu began infilling with estuarine sediments, however, the pollen records from coastal Fiji are probably witness only to the arrival of the sea at its present level. These pollen sites owe their existence to this event, with deposition occurring as beach ridges effectively excluded marine influences from the delta regions. In both the Rewa and Navua Deltas, the ^{14}C dates indicate this event had probably occurred by 4300 BP. Prior to this the estuarine facies in the delta sediments indicate extensive mangrove vegetation, but once marine incursions ceased, the delta vegetation was apparently dominated by *Metroxylon vitiense* swamps. Developments in the delta regions since 4300 BP are probably reflections of sedimentary processes rather than any further sea level fluctuations. There is no evidence in either the pollen records or the stratigraphy to substantiate the ideas of Schofield (1970) and Matsushima *et al.* (1984) that sea level has been higher than the present in the past 4000 years in southern Viti Levu. All of the features described by them fall within the range of the maximum high tide levels in the region, especially those associated with cyclonic events, and may thus be a reflection of such events.

As sediments accumulated and more organic material was deposited, the *Metroxylon* probably moved to more suitable substrates at the back of the deltas where the taxon survives at present. Human activity may have played a role in the disappearance of *Metroxylon* from the pollen records and this is discussed below.

Peat swamps subsequently developed in the lowest areas of the deltas which had experienced impeded drainage and the vegetation was largely *Pandanus* swamp. This change occurred at various times throughout the deltas, varying from 2300 BP at Vunimoli, 1400 BP at Bonatoa, and 1000 BP at Raralevu.

7.3 Tectonic and Volcanic Activity

It was postulated that the Wainisavulevu Creek deposit may have accumulated because of damming of the creek by minor tectonic tilting. The nature of the sediments indicated this was an ephemeral phenomenon and no major disruption of the vegetation is implied. On Taveuni, tectonism is likely to be the major cause of land slides and the associated intermittent disruption of the vegetation. The sustained presence of taxa indicative of disturbance in an otherwise pristine forest environment is likely to be a reflection of such tectonic activity. It might also help explain the long period taken to achieve stability in the forest vegetation near Tagimaucia.

More substantial disruption of vegetation is likely to ensue after volcanic eruptions and the ash fall recorded in the Tagimaucia sediments at about 1500 BP resulted in substantial wetland vegetation change and more limited dryland vegetation change. The influx of nutrients to the otherwise oligotrophic Tagimaucia swamp and lake system resulted in a massive expansion of swamp vegetation into open water areas and the rapid deposition of organic sediments in those areas. This changed the mode of pollen input to the pollen site and thus changed the composition of the dryland pollen spectra. Some disruption of the catchment vegetation probably occurred at the time, but there is no evidence of this disturbance at the present.

7.4 Human Impact on the Fijian Environment

Archaeological records from Fiji indicate the presence of humans in the islands from at least 3200 BP. Their impact on the environment is very clearly demonstrated in the sedimentary and pollen records from the sites in central and coastal Viti Levu and there emerges a coherent pattern of environmental change due to anthropogenic disturbance on this island, and this has been summarised in Table 7.1.

At the time of european contact with Fiji, two distinctive patterns of human impact were evident. In the drier, leeward parts of the main islands, vast areas of grass and fernland dominated the landscape; soils were poor and often eroded. It has been suggested that these *talasiga* lands were degraded as a result of the slash and burn agricultural practices of the early occupants, but that they had since been largely abandoned. In contrast, very high concentrations of people lived in fortified villages in the delta regions of windward Fiji and subsisted on the products of complicated wetland agricultural systems.

The available prehistoric evidence suggests the earliest migrants to Fiji developed coastal village sites where both coastal and dryland resources could be exploited. Dryland agricultural practices spread inland from these sites, probably utilising slash and burn methods. Sedimentary and carbonised particle data from Lakeba indicate that anthropogenic burning and human induced accelerated erosion and deposition began by 2000 BP (Hughes *et al.* 1979; Hughes 1985). The dates for intensified land-use and the development of fortifications in the lowlands are

Table 7.1: Human Impact on the Fijian Environment

Date (yrs BP)	Dryland	Wetland
4000-3000	Some burning in the Rewa catchment.	Exploitation of *Metroxylon* swamp, increasing through time to about 3000 BP.
3000-2000	Extensive coastal settlement - village sites with artifactual evidence of lagoonal, reef and horticultural resource base.	Drainage systems for hydrophytic crops established in the Rewa Delta. *Metroxylon* diminished as a resource because of changed delta hydrology.
2000-1500	Expansion of population throughout Fiji and inland on the main islands. Widespread deforestation by fire, followed by accelerated erosion.	Expansion of environments suitable for wetland cultivation at coast - at Lakeba, Navua and Rewa. Establishment of fortifications in the Navua Delta.
1500-1000	Populations decreasing in dry, inland areas. Dryland degradation increases in the Rewa Delta region.	Population increasing at the coast. Fortified villages on Taveuni and Lakeba.
1000-1800AD	Inland areas largely abandoned. Development of powerful political village units at the coast.	Dense population at coast exploiting wetland resources and establishing extensive wetland agricultural systems.

presently speculative. ^{14}C dates from Taveuni indicate the upland fortifications there are at least 800 years old (Frost 1974). It is suggested the delta sites are probably older and pottery associations indicate a time-depth of 1500 years (G. Irwin personal communication 1986). Incursions of new migrants and subsequent pressures on the resources of land and food have been suggested as the reason behind development of the fortifications, especially as the 800 BP date coincides with the attrition of new styles in ceramic assemblages. However, the estimated age of 1500 years for the Navua Delta fortifications implies that development as a response to *in situ* pressures is more likely.

The vegetation and fire histories presented in Chapters 5 and 6 shed some light on Fijian prehistoric events. In the coastal regions, burning, which may have been anthropogenic in origin, is evident from about 4300 BP. The impact of this burning on the catchment vegetation was apparently minimal until about 3000 BP, when there was replacement of forest by grasslands. The data suggest increasing human impact through time, perhaps reflecting an increasing population. It is possible that Bonatoa was an attractive settlement site in its earliest phase because of the significant food resources available in the sago swamp. The reduction in the pollen representation of sago from 1400 BP may be the result of a combination of the management of the sago as a staple food crop (which would reduce pollen production or cause it to cease), coastal progradation and delta formation (which would reduce the habitat for *Metroxylon*). This may have been accompanied by more extensive human activity on dryland, resulting in increased sediment transport to the delta area. It is most likely that the *Metroxylon* resource was diminished as the delta developed, perhaps partly because of dryland anthropogenic disturbance, and reliance on *Metroxylon* as a food probably also diminished. However, the changes in delta configuration and sediments probably favoured extensive cultivation of other hydrophytic crops, including taro. In the Navua Delta the later period of settlement may indicate that *Metroxylon* was not initially used as a food staple, but that delta development had already provided suitable habitats for intensive taro cultivation. The reduction of *Metroxylon* in the Vunimoli pollen diagram to the present may indicate the gradual migration of the taxon towards the back of the delta as peatlands became established.

By 2000 BP, the Raralevu evidence for a mosaic of forest, secondary forest and grassland vegetation on dryland in the Rewa Delta suggests either less substantial clearing had occurred inland, or that the area had been abandoned and was currently recovering. The parallel channels in and around Raralevu were interpreted as evidence of former wetland management in the area, which by 2000

BP had been abandoned. This strongly suggests that the dryland vegetation pattern is also a reflection of recovery after a period of land-use. The reason for abandoning the Raralevu area may well have been related to natural changes in delta morphology such that Raralevu was no longer suitable for agriculture, or other areas became more attractive. The vegetation histories from the Rewa Delta sites suggest that land-use in the area shifted, probably as the delta system was developing.

On the Nadrau Plateau, at the eastern margin of the *talasiga*, deforestation associated with anthropogenic burning occurred at about 2000 BP. This burning activity was sustained until about 1000 BP when firing apparently diminished and a mosaic of grassland and secondary forest became common. It is likely that people moved out of the area, perhaps because environmental degradation had progressed to the extent where agriculture was no longer viable, or because more attractive opportunities for agriculture were presented elsewhere.

Intensification of agricultural activity in the lowlands seems to date from about this period, that is 1500 to 1000 BP. Although the data are fragmentary, this coincidence of dates might indicate that the abandonment of inland, dryland agricultural practices was related, at least in part, to the development of intensive wetland cultivation in the lowlands. On Lakeba, there is some evidence to suggest that dryland activities were reduced after an initial phase of extensive burning and clearing, and that more intensive activity in the lowland swamp environments followed (Hughes *et al.* 1979). Populations were maintained inland on the main islands, but little is said of these "kai colo" in ethnographic records and there was little friendly interaction between these people and the coastal communities (Scarr 1984), rather each group targeted the other in frequent raids and subsequent cannibal activities.

It was suggested by Ash and Ash (1984) that many of the freshwater wetland ecosystems on Viti Levu had an anthropogenic origin. Increased erosion from the slopes because of deforestation may have effectively blocked many valleys and created or extended the wetland environments. The combination of forest clearance, occasional cultivation and burning was probably sufficient to create peat bogs in areas of naturally impeded drainage (Ash and Ash 1984). This is indicated for Nadrau Swamp, although there is no evidence to suggest the area was subsequently used for wetland cultivation, possibly because the peaty substrate which quickly formed was unsuitable for hydrophytic crops.

The extensive delta regions of Viti Levu owe much of their development to the post-glacial rise in sea level, but it is possible that human activities in the catchments may have contributed to some of the features, especially the amount of sediment available for rapid deposition and levee formation. While the build-up of levees provided suitable substrates for wetland agriculture, it also probably resulted in the development of peatlands and the ultimate demise of the food plant, sago. It might be expected that this increased sedimentation would be even more significant in the river systems of leeward Fiji, where the most extensive dryland disturbance is evident, however, the coastal geomorphology in this area generally precludes the development of extensive deltas.

There are other indications of human-induced landscape change in Fiji. Large areas of fringing coral reef flats have been killed by the deposition of alluvium in leeward Viti Levu (Ash in prep. b) presumably the result of the massive clearing activities inland. The sand dunes at the mouth of the Sigatoka River, whose catchment extends to the edge of the Nadrau Plateau, are also thought to derive from accelerated erosion of topsoil following anthropogenic disturbance. On Lakeba, Hughes *et al.* (1979) and Hughes (1985) have indicated that the large scale formation of many swamps may have begun only after the arrival of people and the onset of clearing and burning in the catchments. It is postulated that either by design or accident, the consequent accelerated erosion and deposition extended the environments for wetland taro cultivation.

In the 1500 years to the present, there has apparently been a continued intensification in agriculture, especially in the coastal lowlands. The forfified village sites probably developed as a result of increased population, the centralisation of the population into powerful political units, and the need to defend the extensive resource base necessary for survival. By at least 800 BP, such fortifications and the presumably related social-political framework had extended to other islands in Fiji, for example Taveuni (Frost 1974) and Lakeba (Rowland and Best 1980).

At the time of european contact, powerful chiefdoms were spread throughout Fiji, mainly in the coastal areas, although little was known of the inland populations. The *talasiga* formation was widespread in leeward Fiji and on the smaller islands, but there was little evidence of continued cultivation in these areas. Most of the *talasiga* lands were too degraded to support agriculture without intensive modification of the environment via irrigation and terracing. In some places, however, diminished human activity, especially burning, has resulted in the partial recovery of the vegetation, for example, on Lakeba (Hughes 1985) and there is some evidence in the Nadrau pollen diagram to suggest this also.

7.5 Summary

The information presented above may be summarised into a general picture of environmental change in Fiji, and this is presented as a table (7.2) below.

Table 7.2: Late Quaternary Environmental Change in Fiji

Period (yrs BP)	Vegetation		Wetlands	Climate	Sea Level	Human Impact
	Windward Fiji	Leeward Fiji				
23 000	Widespread gymnosperm forests with angiosperm understorey indicative of cloud forest conditions.	Widespread grasslands with pockets of open woodland in more sheltered locations.	Tagimaucia basin mostly open water? Coastal swamps restricted because of low sea level. Perhaps widespread small swamps on Nadrau Plateau because of tectonic activity.	Cool(-2 C) and cloudy. Cloud base lower than present, but precipitation more seasonal, thus arid conditions in leeward Fiji.	Islands more extensive and numerous than present. Viti Levu joined to Yasawas, Taveuni joined to Vanua Levu. Extensive areas of exposed older reef.	
14 300–13 000	Widespread gymnosperm forest with *Ascarina* and treeferns as understorey.	Widespread grasslands and fernlands.	Extensive open water in Tagimaucia basin. Coastal swamps still restricted.	Cooler (-4 C?), less cloudy. Southern Oscillation weak and south-east trades less persistent. Tropical disturbances uncommon. Seasonal rainfall in windward Fiji.	Reduction in size of islands. Vanua Levu and Viti Levu separate from smaller islands.	
13 000–9000	Gymnosperm forest with cloud forest type understorey similar to forest at 23 000 BP.	Perhaps increase in extent of open woodlands.	Increase in fringing swamp at Tagimaucia.	Conditions ameliorating and similar at 13 000 to 23 000 BP. Southern Oscillation stronger and south-east trades persistent. Precipitation seasonal.	Sea level rising rapidly. New base levels affecting surface features of small islands. New reefs forming.	
9000–4000	Gymnosperm forests become less common and present mixed angiosperm forest established by end of period.	Open woodland in most places, perhaps pockets of grass and fernlands on poorer soils.	Extensive swamp in Tagimaucia basin. Onset of swamp formation at coast as sea level rose.	Present means of temperature and rainfall established. Present annual distribution of rainfall also achieved.	Sea level rising to present level between 6000 and 4000 BP. Present distribution and size of islands established.	
4000–3000	As above.	As above, but perhaps clearing and burning in coastal areas resulting in more widespread open grassland.	Tagimaucia basin swamp as above. Development of coastal *Metroxylon* swamps due to rise in sea level, formation of beach ridges and possibly human activity inland.	As above	Sea more or less at present level.	Possible arrival of humans. Some burning in windward Fiji (Rewa Delta). Possible clearing on hillslopes near coast in leeward Fiji. Population established at several sites around Fiji by end of period.
3000–present	As above.	Spread of *talasiga* lands to the Sigatoka/Rewa divide in Viti Levu and probably throughout the smaller inhabitated islands.	Area of swamp vegetation dramatically increased at Tagimaucia after ash fall at 1500 BP. Coastal swamps change to dominantly *Pandanus* from 2000 BP, and become peat-forming. Swamps develop inland on Viti Levu perhaps as a response to increased sediment transport off cleared slopes.	As above.	As above.	Increased human impact in leeward zone of Fiji possibly to 1000 BP then abandonment. Agricultural practices in delta regions increasing and intensifying, probably after 1500 BP until the present.

CHAPTER 8

THE FIJIAN RECORD OF ENVIRONMENTAL CHANGE IN AN AUSTRALASIAN CONTEXT

This chapter attempts to relate the Fijian record of environmental change, summarised above in Table 7.2, with the information available from elsewhere in the Australasian region, which was reviewed in Chapter 1. The data may be discussed in terms of patterns of vegetation change and climate, sea level records, and the effects of anthropogenic disturbance on the environment.

8.1 The Vegetation and Climatic Record

At the height of the last glaciation, the Australasian region experienced much cooler and drier conditions. At high elevations in the tropics, and in temperate areas, the cooling, in the order of 6 to 10°C below present means, was most marked. As a result, the extent of glaciers in Borneo, (Flenley and Morley 1978), New Guinea (Loffler 1982), New Zealand (Chinn 1983), south-eastern Australia (Bowler *et al.* 1976) and Hawaii (Porter 1979) was increased and treelines were generally lowered as a response to the different climatic regime. In Sumatra, upper montane forest had a greater range than present (Maloney 1980, 1985; Morley 1982a), and in New Guinea, subalpine forests were restricted in area, although upper montane forest and alpine communities were more widespread (Hope 1980). In temperate Australia and New Zealand, alpine grasslands and herbfields occupied the upland areas and more open communities prevailed at lower elevations (Kershaw *et al.* 1983a; McGlone 1985). In tropical areas, the amount of temperature reduction implied from terrestrial records for the glacial maximum is far greater than that predicted by CLIMAP (1976, 1981), based on the interpretation of Pacific Ocean cores. None of the explanations given for this discrepancy applies in all cases and the suggestion of Webster and Streten (1978), Aharon (1983), and Rind and Peteet (1985) that the CLIMAP estimates are simply too conservative may be an appropriate interpretation.

At lower elevations in the tropics, the height of the last glaciation was characterised by substantially more arid conditions. This has been recorded in the lower latitudes of South America, Australia, India and Africa (Williams 1975, 1985;

Flenley 1979a; Rind and Peteet 1985). On the Atherton Tableland in north-eastern Australia, there was perhaps a 50% reduction in precipitation from present means and the replacement of rainforest by sclerophyll vegetation (Kershaw 1983a). More arid conditions are implied across northern Australia by the activation of dunes in the Lakes Gregory and Woods basins (Bowler 1978) and the Fitzroy River estuary (Jennings 1975), which are tentatively correlated to the last glaciation (Bowler 1983b). In the Pacific, aridity is suggested on Easter Island between 21 000 and 12 000 BP (Flenley and King 1984), on the Galapagos Islands from >34 000 to 10 000 BP (Colinvaux 1972; Colinvaux and Schofield 1976), on Aneityum Island in Vanuatu at 23 000 BP (Spriggs 1981), and perhaps on Lakeba in Fiji, although this is undated (Latham 1979).

In Fiji there is no palynological data which refer directly to the period of maximum glaciation, but the immediately pre- and post-glacial periods are represented in the Wainisavulevu Creek and Lake Tagimaucia pollen sequences, respectively. The vegetation types represented in these records are suggestive of conditions very much drier than the present. Extensive gymnosperm forest near Wainisavulevu at 23 000 BP with an understorey of taxa currently restricted to ridges and mountain tops, is suggestive of a seasonal precipitation regime, perhaps with the average cloud base at a much lower elevation than it is at present.

The Lake Tagimaucia data suggest that conditions between 14 300 and 13 000 BP deviated even more substantially from present means. Extensive gymnosperm forests apparently occupied central Taveuni, which suggests a massive reduction in precipitation and especially an increase in its seasonal distribution. Cloud forest elements, apart from *Ascarina*, are rare in the pollen spectra which substantiates the claim for relative aridity. Between 2 and 4°C of temperature reduction is envisaged for the period 14 300 to 13 000 BP and since this is the post-glacial period, it is not representative of the most extreme conditions. A further temperature reduction during the glacial period might be postulated, but a further reduction in precipitation seems unlikely.

As far as can be ascertained, the Fijian data correspond well with the pattern of glacial climates emerging from the Australasian region. The proportion of precipitation reduction implied by the Tagimaucia vegetation history is comparable with that from the Atherton Tableland (Kershaw 1976; 1983a), although the actual amount is greater at Tagimaucia. The comparison is significant because both areas are at a similar latitude and altitude, but Atherton is continental in nature (and even more so during the period of glacial low sea level). The comparable degree of precipitation reduction implies zonal aridity, and the contemporaneous increase in the continental nature of Atherton may have had little further impact on the local climate at the height of the glaciation. Rind and Peteet (1985) simulate a similar proportion of precipitation reduction during the last glaciation in the western Pacific in their general circulation model.

The mechanisms for the global cooling have been discussed (Chappell 1974; Bradley 1985) and the impact of this cooling on the circulation patterns of the Australasian region are at least partially understood. At the time of maximum temperature reduction, when an enlarged area of sea ice surrounded Antartica, sea surface temperatures in low latitudes would have been reduced (Webster and Streten 1978). Nix and Kalma (1972) noted the significant role played by sea surface temperatures in rates of evaporation and the transport of moisture and energy as latent heat. During times of maximum cold, the moisture carrying capacity of winds over the oceans of Australasia would be reduced and presumably so would the genesis of summer storm activity, both major (i.e. cyclones) and minor disturbances. Salinger (1981) has noted that during the glacial period, the Southern Oscillation would have had a low index which suggests the south-east trade winds would not be persistent at this time. In combination, these data indicate that areas which presently receive the bulk of their precipitation from either the south-east trade winds or from summer disturbances would be substantially drier at the glacial maximum. The correspondence between the Fijian and north-east Queensland data is therefore expected - zonal aridity between 17 and 19°S is a consequence of the changes in circulation described above.

Sea surface temperatures began to increase from 15 000 BP (Shackleton and Opdyke 1973; Hays 1983) and terrestrial post-glacial climatic amelioration began at 16 000 to 15 000 BP in New Guinea (Walker and Flenley 1979; Loffler 1982), by 15 000 BP in south-eastern Australia (Kershaw *et al.* 1983b; Singh and Geissler 1985) and by 14 500 BP in New Zealand (McGlone 1983b). In contrast, increases in precipitation on the Atherton Tablelands did not occur until 10 500 BP in the east of the area and 7200 BP in the west (Kershaw 1983b). It is in this instance that the effect of the nearby continental shelf is most convincingly demonstrated. At the glacial maximum the sea was at least 140 m below its present level and the wide continental shelf was exposed. Most of the near shore and reef zone is less than 35 m below present sea level and would have remained exposed until at least 9500 BP (Ash 1983). During the period between 9500 and 7000 BP, the shelf was gradually flooded, initially with very shallow, warm water. There was an associated increase in cyclone related rainfall in the Gulf of Carpentaria. Rainfall presumably increased only when the shelf was flooded, since Atherton would have been a considerable distance from the coast prior to this and, while the tablelands would still have induced uplift of the winds, it is possible that convective cells formed over the exposed shelf causing the moist winds to deposit their precipitation before reaching the higher elevations. Although, as was mentioned above, there may have been a regional reduction in precipitation which was more important than any local effects.

Other areas experienced less change in their proximity to the coast, because of steeper and narrower coastal shelves (e.g. south-eastern Australia and New Zealand) and climatic amelioration, which was largely temperature related in these regions, occurred as sea surface temperatures rose. The Fijian record is also probably representative of a direct response to rising sea surface temperatures and the establishment of a stronger Southern Oscillation. Presumably as the temperatures increased and the south-east trade winds became more persistent, conditions ameliorated towards the present means. The vegetation history from Lake Tagimaucia implies the mean cloud layer had fallen below the elevation of the lake from about 13 000 to 9000 BP. This is lower than its present mean position and suggests that although temperatures were rising, they may have remained lower in the immediate vicinity of Lake Tagimaucia because of decreased radiation. Such a situation may have prevailed on the windward side of many high islands of the south-west Pacific. The Fijian record suggests the rise in temperature was gradual to 9000 BP, which is similar to Morley's (1982a) interpretation of the Sumatran data, and that the establishment of present conditions was reliant upon the persistence of the south-east trade winds, and hence the establishment of modern sea surface temperature values.

The post-glacial climatic optimum which is implied in the vegetation histories from New Guinea, tropical and temperate Australia, New Zealand and Hawaii, is not reflected in the Tagimaucia pollen diagram. An overall increase in sea surface temperatures is proposed by Hays (1983) for the southern oceans at about 9000 BP. This warming may explain the more equable climates experienced in those places, and in northern Australia and New Guinea the effect would be enhanced by the mechanism proposed by Nix and Kalma (1972). They suggest that after sea level began to rise, but before Torres Strait was flooded, the movement of the cooler Equatorial Current across the continental shelf was prevented. Large areas of shallow, warm water would then exist close to the landmasses, favouring latent heat transport and convective mechanisms. Temperatures and precipitation would increase over the nearby continental areas. This would probably be most obvious in the Atherton area of north-east Queensland where much of the rainfall derives from the south-east trade winds which pass over the wide continental shelf.

This mechanism is obviously absent from the Fijian region, although the increased sea surface temperatures were presumably experienced. Perhaps the degree of climatic change was insufficient to elicit a vegetation response in the already climatically equable Tagimaucia area, although a long vegetation record from an area with a climate more marginal for forest growth, for example leeward Fiji, might show changes in Holocene climates. Without the additional impact of ponded warm, shallow seas, the tropical areas in northern Australia and New Guinea might also have failed to respond to the minor warming of sea surface temperatures. The vegetation in temperate regions in Australasia was probably more sensitive to minor climatic changes at this time.

The post-glacial record from Kerinci in Sumatra (Morley 1982a) tends to substantiate this interpretation. Temperatures some 2°C below present are recorded before 10 000 BP, with a subsequent climatic amelioration to about 8600 BP. No climatic optimum is recorded, and Morley suggests that the floristically complex Kerinci area may preclude palynological resolution of minor vegetation changes, or that the effect of such climatic changes might not have been felt at low altitudes (ca. 950 m asl). The data from the Atherton Tableland (Kershaw 1981) at 750 m asl tend to contradict the last statement, but as was noted above, the post-glacial climatic fluctuation may have been of greater amplitude in this area. In addition, the Atherton area is more marginal for rainforest growth and the vegetation is probably more sensitive to any changes in the climate.

In Hawaii, the post-glacial climatic optimum (although this is undated) is reflected in the expansion of warmth-demanding taxa at high elevations. Again the response of vegetation in this more extreme environment was probably greater than would have been experienced at lower elevations with an established equable climate.

8.2 Sea Level History

There is little argument over the movement of sea level during the late Pleistocene-early Holocene, but there is some controversy over sea level changes in the past 6000 years or so. While Chappell (1982) is able to confidently state that there have been no eustatic sea level fluctuations of 1 m or more during the past 6000 years, vastly different sea level records have been obtained from various coastlines because of localised tectonic movements and more regional isostatic responses to the increased volume and weight of the oceans.

In the Pacific region it might be assumed that, in the absence of tectonic activity and wide continental margins (which flex under the additional weight of water as sea level rises), a sea level curve reflecting eustatic changes might be obtained. The Caroline Islands in the aseismic western Pacific were chosen by Bloom (1970) to test this, and his results from the eastern Caroline Islands suggest a steady rise in sea level during the past 6000 years to its present level. A similar curve was derived from Hawaiian data (Euston and Olson 1976). Data from the western Caroline Islands indicated coastal emergence, but this may be attributed to uplift in the area, and need not contradict Bloom's conclusions (Easton and Ku 1980). On the other hand, Schofield (1977) examined and dated coastal features in Kiribati and Tuvalu (Gilbert and Ellice Islands) to the east of the Caroline Islands, and concluded that a series of sea level fluctuations, both above and below the present mean, had occurred during the past 4000 years. He suggests that this might be the result of differential salinity levels and densities between high and low latitudes as glacial ice melted. Schofield is in favour of a similar sea level curve for Fiji (Schofield 1970). Matsushima *et al.* (1984) describe sea level fluctuations above and below present means from the south coast of Viti Levu.

The data presented in this thesis contradict the findings of both Schofield (1970) and Matsushima *et al.* (1984) for southern Viti Levu. The palynologic and stratigraphic records and ^{14}C dates indicate that present sea level was achieved at about 4300 BP and has not risen above that level since then. The Fijian sea level record thus resembles the curves produced by Bloom (1970) and Easton and Ku (1980).

8.3 Human Impact

Spriggs (1985) has recorded a prehistoric sequence of settlement and subsequent landscape change on Aneityum, in Vanuatu, which he believes may be a common one on many oceanic islands in the south-west Pacific. The initial inhabitants probably concentrated their agricultural activities on hillsides near the coast and perhaps exploited the swampy valley bottoms for taro production. Clearing and burning continued inland, causing accelerated erosion which laid bare the coastal hillsides and left them useless for gardening, although these hillside soils were generally infertile in the first place and needed extensive terracing to allow any sustained gardening. However, the alluvial soils created in the valley bottoms and on the coastal plains were (and are) fertile and provide an environment eminently suited to intensive taro cultivation. Similar sequences have been recorded in Hawaii (Kirch and Kelly 1975), Tikopia (Kirch and Yen 1982), Futuna (Kirch 1981) and suggested for Lakeba (Hughes *et al.* 1979; Hughes 1985).

These records of environmental modification are from small island ecosystems, where the effects of anthropogenic disturbance are most likely to be severe. Hughes

(1985) summarises the geomorphic data from several small catchments in Papua New Guinea and arrives at similar conclusions as Spriggs (1985); that is, agricultural practises on the catchment slopes resulted in sediment accumulation in the valley bottoms and in some cases this was accompanied or followed by modification of the swampy valleys for agriculture. Oldfield *et al.* (1985) document increases in lake sedimentation during the more recent past, which are probably related to agricultural intensification following the introduction of the sweet potato to the Papua New Guinea Highlands.

The data presented in this thesis suggest that the impeded drainage responsible for the formation of Nadrau Swamp was closely related to anthropogenic disturbance in the small catchment. There is no indication that the swamp was subsequently put to agricultural use, but this may be because the peat substrate which quickly built up was unsuitable for cultivation. On the other hand, the coastal sites discussed above are the depositional sinks of much larger systems than those reviewed by Spriggs (1985), Hughes (1985) and Oldfield *et al.* (1985) and it is likely that anthropogenic disturbance has simply enhanced the natural processes of delta formation. However, as Ash and Ash (1984) suggest, the peatlands and their open vegetation which persist in parts of the deltas, and have done so for the past 1500 to 1000 years, may be attributed to a combination of deforestation, cultivation and burning.

A more general view of the palynological data suggests that a pattern of inland settlement with slash and burn agriculture followed by abandonment and then intensive wetland cultivation exists in Fiji, but that it was mainly the leeward, dry areas which were abandoned. The Nadrau Swamp pollen diagram implies the partial recovery of woody vegetation is related to a decrease in burning, perhaps because people had moved out of the area. This is also the case on Lakeba. On the other hand, the Rewa Delta sites imply that exploitation of the extensive wetland sago resource was likely from the earliest phase of settlement, and drainage of the swampy areas at Raralevu for taro cultivation probably occurred before 2000 BP. Large areas suitable for taro production have probably existed throughout the period of human occupation in the Rewa Delta at least. Dryland environments nearby probably continued to be disturbed to the present. This is perhaps a reflection of the very high overall population in this area, but perhaps also because the degree of dryland degradation was not so great as to render it unsuitable for some form of cultivation. The high rainfall may have enabled terracing of the hillsides and dryland cultivation of taro, and the soils may be inherently more fertile than those in leeward Viti Levu, which is geologically older. A comparison of the Rewa and Navua data suggests more intensive, and probably extensive, use of the delta areas was made after 1500 BP.

An additional common feature throughout many islands of the south-west Pacific, including Fiji, is the presence of large tracts of vegetation dominated by grass and ferns, especially on leeward slopes of the main islands and on the smaller islands. There is a relationship between these vegetation types and relatively low rainfall and it is likely that their distribution is related to the greater susceptibility these areas have to environmental disruption of any kind. However, it has been suggested in this thesis that environmental conditions at the height of the last glaciation may have been severe enough in these areas in Fiji to allow natural development of the grass and fern formations. Although the subsequent climatic amelioration probably allowed the establishment of woody communities in these areas, pockets of *talasiga* type vegetation may have persisted where soils were poor. The broad scale distribution of *talasiga* which exists at present may have expanded from this more limited natural distribution as anthropogenic disturbance spread. The Nadrau data show that forest existed prior to human interference in the wetter parts of leeward Fiji. Hughes *et al.* (1979) suggest that the smaller island of Lakeba supported an area of *talasiga*-like soil and vegetation prior to the arrival of humans.

This is possibly the case on many islands of the south-west Pacific. The changes in climate postulated for the glacial maximum in Fiji are the result of changes in the general circulation pattern which would affect the local climate of most major island groups in the south-west Pacific. Islands which presently have drier climates than Fiji may have experienced even more severe conditions at the glacial maximum. Grasslands may have been common providing a source for the widespread grasslands, herbfields and fernlands of the present.

8.4 Concluding Remarks

The long-term vegetation changes which are demonstrated by the Fijian palynological records are a result of external environmental change. Plant communtiy composition reflects the available plant taxa at any one time.

The vegetation changes suggest that there has been significant climatic change in the Fijian region over the past 23 000 years. The degree of change implied is comparable with results from elsewhere in the Australasian region and substantiates the concept of instability in tropical environments on a wide range of timescales. Glacial aridity is indicated by the Fijian data and the regional mechanisms which probably contributed to this are likely to have affected most of the archipelagoes in the south-west Pacific. It is considered that a reduction in regional sea surface temperatures is necessary to explain the substantial reduction in precipitation and increase in its seasonality which is implied.

The vegetation changes demonstrated by the Fijian data do not represent changes in gross distribution of present day communities, rather there are combinations of taxa unlike those which are now extant, until quite recent times. Continued tectonic activity is also likely in the Tagimaucia area. Because of these factors it is difficult to discern any lag time in vegetation response to climatic changes - changes in forest composition were obviously ongoing from the earliest pollen records until about 6000 BP. By this time the Taveuni forests were very similar to the present and by at least 4000 BP the coastal forests had gained their present composition.

It would seem that the vegetation of the glacial period in Fiji was characterised by extensive gymnosperm forests in the wetter areas and perhaps grasslands/open scrub in the drier areas. Gymnosperm forests are still common on Vanua Levu and upland western Viti Levu, but the understorey is different from that which is implied in the fossil pollen records. Taxa which are presently common on exposed and cloudy ridge and mountain tops apparently found a niche in the gymnosperm forest understorey in the past. This does not require any long-range migration of taxa: cloudy ridges are scattered throughout upland Fiji, wherever exposure to the prevailing winds occur. This implies the gymnosperm forests may have been relatively open. This is seen in very cloudy areas in Irian Jaya, possibly as a result of nutrient or radiation depletion (Hope 1980). Heavy cloud cover with concomitant high humidity characterises these environments and it is possible that the potential regional cloud layer was lower in the past, at least for the immediately pre- and post-glacial period. It may have been absent at the height of the glaciation. With a lowering of the cloud layer these taxa were probably able to expand into these more favourable habitats. Taxa which are common in the rainforests near Tagimaucia at present were never completely absent, so the vegetation shifts implied by the pollen diagrams are not great. The dissected terrain of Taveuni and upland Viti Levu must have provided suitable microhabitats, at least for most taxa, throughout the Pleistocene.

Local extinctions in Fiji apparently included *Dacrydium* and *Dacrycarpus*, which are not now recorded from Taveuni, but are very common nearby on Vanua Levu. *Quintinia* has not been recorded for Fiji, nor any other Saxifragaceae, but the fossil pollen samples suggest it was present in the past. The population sizes of such taxa as *Ascarina* and *Balanops* are presently at their minimum for the period covered by the pollen records. Their current restriction to ridges and peaks suggests that they are in no danger of local extinction, but may be able to take advantage of any reversal of conditions towards glaciation.

Human impact on the Fijian environment has been significant during the period of occupation. In windward Viti Levu, forested areas in the immediate vicinity of settlement sites were reduced to grassland or a mixture of grassland and secondary forest taxa. The wetland environments were manipulated to increase production of hydrophytic crops and it is likely that little natural vegetation remains in the delta regions.

In leeward Viti Levu there is palynological evidence to suggest that forest was replaced by grassland, at least near the present forest/*talasiga* boundary. More open forest communities probably persisted in western Viti Levu until the arrival of humans, but it is possible that restricted areas of natural grassland existed where soil fertility was low. It is also likely that grassland was common in leeward Fiji at the height of the last glacial maximum. While the expansion of grasslands has undoubtedly occurred since humans arrived in Fiji, there would appear to have been precursors of this vegetation type present in the Fijian vegetation. The dominance of taxa introduced since european settlement in the present *talasiga* vegetation suggests that the greatest expansion of the grasslands may have occurred only in the past 150 years.

There is obviously potential for continued palynological research both in Fiji and in other islands of the south-west Pacific. Extension of the long-term record of environmental change is desirable and should be possible with further coring at Lake Tagimaucia. Plans are already made to continue the coring program. A longer record of vegetation history in the drier environments of leeward Fiji might substantiate the claims made in this thesis, and those by Latham (1983) and Hughes (1985), that the *talasiga* vegetation is only partly a reflection of anthropogenic disturbance. It was also suggested above that any minor climatic fluctuations during the Holocene may have had more impact on the vegetation in leeward Fiji because of its less equable climate. The need to extend investigation into leeward sites on the main islands is therefore clear. Possible sites for this exist in the Dreketi Valley in Vanua Levu and near Sigatoka in Viti Levu.

The detailed history of human impact on the environment which was revealed in several of the Fijian pollen sites, indicates the potential the technique has for elucidating such environmental histories on other south-west Pacific islands. The spread of the Lapita people throughout island Melanesia and Western Polynesia, with their agricultural skills has aroused much interest. Since similar patterns of environmental change following settlement have been documented from several different island environments, palynological investigations may provide information on dates of arrival and agricultural activities where more direct evidence is elusive.

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[1] This article was published in my former married name, W. Ash.

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*corrigendum: Whitehead, J.C. 1984 should read Newsome, J.C. 1984.

APPENDIX A

AUTHORITIES OF SPECIES MENTIONED IN THE TEXT

BRYOPHYTA

Leucobryum sanctum (Brid.) Hampe
Sphagnum cuspidatum Ehrh. ex Hoffm.

PTERIDOPHYTA

ASPIDIACEAE
Lomogramma cordipinna Holtt.

BLECHNACEAE
Blechnum orientale L.
Stenochlaena palustris (Burm.) Bedd.

CYATHEACEAE
Cyathea alta Copel.
C. lunulata (Forst.) Copel.
C. medullaris (Forst.) Swartz

DAVALLIACEAE
Davallia fejeensis Hook.
Nephrolepis biserrata (Swartz) Schott
N. hirsutula (Forst.) Presl.

GLEICHENIACEAE
Dicranopteris caudata (Copel.) St John
D. linearis (Burm.) Underwood

LYCOPODIACEAE
Lycopodium cernuum L.
L. squarrosum Forst.f.

MARATTIACEAE
Marattia smithii Mett.

OSMUNDACEAE
Leptopteris wilkesiana (Brack.) Christen.

POLYPODIACEAE
Sphaerostephanos unitus (L.) Holtt.
Thelypteris interrupta (Willd.) Iwats.

PTERIDACEAE
Acrostichum aureum L.
Culcita straminea (Labill.) Maxon
Lindsaea ensifolia Swartz
Pteridium esculentum (Forst. f.) Cockayne

GYMNOSPERMAE

ARAUCARIACEAE
Agathis vitiensis (Seem.) Benth. & Hook.f. ex Drake

CYCADACEAE
Cycas rumphii f. *seemannii* (A.Braun) Kanehira

PODOCARPACEAE
Dacrycarpus imbricatus (Blume) de Laub.
Dacrydium nausoriense de Laub.
D. nidulum de Laub.
Podocarpus neriifolius D.Don ex Lamb

ANGIOSPERMAE - MONOCOTYLEDONAE

ARACEAE
Alocasia macrorrhiza (L.) G.Don
Amorphophallus paeoniifolius (Dennst.) Nicholson
Colocasia esculenta (L.) Schott
Cyrtosperma chamissonis (Schott) Merr.
Epipremnum pinnatum (*L.* Engl.

ARECACEAE
Clinostigma exorrhiza (H.Wendl.) Baccari ex Martel.
Cocos nucifera L.
Metroxylon vitiense (H.Wendl.) H.Wendl. ex Hook.f.
M. sagu Rottb.
Physokentia rosea H.E.Moore
Veitchia simulans H.E.Moore

BROMELIACEAE
Ananas comosus (L.) Merr.

COMMELINACEAE
Aneilema vitiensis Seem.
Commelina diffusa Burm.f.

CYPERACEAE
Cyperus difformis L.
C. haspan L.
C. pilosus Vahl.
Eleocharis dulcis (Burm.f.) Trin. ex Henschel
E. ochrostachys Steudel
Fimbristylis dichotoma (L.) Vahl.
F. miliaceae (Rottb.) Beauv.
Hypolytrum nemorum (C.B.Clarke) Koyama
Kyllinga brevifolia Rottb.
K. polyphylla Willd. ex Kunth.
Lepironia articulata (*Retz.* Domin.
Machaerina falcata (Nees) Koyama
Pycreus polystachyos (Rottb.) Beauv.
Rhynchospora corymbosa (L.) Britt.
Scleria polycarpa Boeck

ORCHIDACEAE
Spathoglottis pacifica Reichb.f.

PANDANACEAE
Freycinetia caudata Hemsl.
F. graeffei Martel.
F. storckii Seem.
F. impavida (Hombron and Jacq.) Stone
F. pritchardii Seem.
Pandanus helicopus Kurz.
P. odoratissimus L.
P. pyriformis (Martel.) St John
P. taveuniensis St John
P. whitmeanus Martel.

POACEAE
Brachiaria mutica (Forst.) Stapf.
Dichanthium caricosum (L.) A.Camus
Digitaria setigera Roth. ex Roemer & Schultes
Echinochloa colona (L.) Link
Eragrostis unioloides (Retz.) Nees ex Stend.
Miscanthus floridulus Anderss.
Paspalum conjugatum Berg.

P. distichum L.
P. orbiculare Forst.
Pennisetum polystachyon (L.) Schult.
Sacciolepis indica (L.) A.Chase

SMILACACEAE
Smilax vitiensis (Seem.) A.DC.

STRELITZIACEAE
Heliconia paka A.C.Sm.

TACCACEAE
Tacca leontopetaloides (L.) Kuntze

ANGIOSPERMAE - DICOTYLEDONAE

ANACARDIACEAE
Rhus sandwicensis A.Gray

ANNONACEAE
Cananga odorata (Lam.) Hook.f. and Thoms.

APIACEAE
Centella asiatica Urban

APOCYNACEAE
Alstonia vitiensis Seem.
Ervatamia orientalis (R.Br.) Turrill
Pagiantha thurstonii (Horne ex Baker) A.C.Sm.

AQUIFOLIACEAE
Ilex vitiensis A.Gray

ARALIACEAE
Brassaia actinophylla Endl.
Plerandra insolita A.C.Sm.

ASCLEPIDIACEAE
Hoya diptera Seem. ex A.Gray

ASTERACEAE
Adenostemma lavenia (L.) Kuntze
Ageratum houstonianum Mill.
Crassocephalum crepidioides (Benth.) S.Moore
Mikania micrantha H.B. & K.

BALANOPACEAE
Balanops pedicillata (Guillam.) Helmqvist

CAESALPINIACEAE
Inocarpus fagiferus (Parkinson) Fosberg
Intsia bijuga (Colebr.) Kuntze

CAPPARIDACEAE
Capparis quinifolia DC.

CASUARINACEAE
Casuarina equisetifolia L.

CLUSIACEAE
Calophyllum inophyllum L.
C. neo-ebudicum Guillemin
C. vitiense Turrill
Garcinia myrtifolia A.C.Sm.
G. pseudoguttifera Seem.

COMBRETACEAE
Lumnitzera littorea (Jack) Voigt

CONVOLVULACEAE
Ipomoea gracilis R.Br.
Merremia aegyptia (L.) Urban

CUNONIACEAE
Acsmithia vitiensis (A.Gray) Hoogl.
Geissois imthurnii Turrill
G. ternata (A.Gray)
Spiraeanthemum brackenridgei (A.Gray) C.Muell.
S. katakata Seem.
S. serratum Gillesp.
Weinmannia affinis A.Gray

DEGENERIACEAE
Degeneria vitiensis I.W.Bailey & A.C.Sm.

DILLENIACEAE
Dillenia biflora (A.Gray) Martinelli ex Dur. & Jacks.
Hibbertia lucens Brogn. & Gris.

EPACRIDACEAE
Leucopogon cymbulae Labill.

EUPHORBIACEAE
Acalypha rivularis Seem.
Aleurites moluccana (L.) Willd.
Bischofia javanica Bl.
Endospermum macrophyllum (MUell.Arg.) Pax & K. Hoffm.
Macaranga harveyana (Muell.Arg.) Muell.Arg.
Manihot esculenta Crantz
Omalanthus nutans (Forst.f.) Guillemin

GENTIANACEAE
Limnanthemum indicum Thwaites

GESNERIACEAE
Cyrtandra tempestii Horne ex C.B.Clarke

GONYSTYLACEAE
Gonystylus punctatus A.C.Sm.

GOODENIACEAE
Scaevola floribunda A.Gray

HERNANDIACEAE
Hernandia olivacea Gillesp.

ICACINACEAE
Citronella vitiensis Howard
Medusanthera vitiensis Seem.

LABIATAE
Hyptis pectinata (L.) Poit

LAURACEAE
Cassytha filiformis L.
Cryptocarya hornei Gillesp.

LECYTHIDACEAE
Barringtonia edulis Seem.
B. racemosa (L.) Spreng.

LOGANIACEAE
Geniostoma vitiense Gilg. & Benedict

LYTHRACEAE
Cuphea carthagenensis (Jacq.) Macr.

MALVACEAE
Hibiscus diversifolius Jacq.
H. tiliaceous L.
Urena lobata L.

MELASTOMATACEAE
Astronidium confertifolium (A.Gray) Markgraf
A. degeneri A.C.Sm.
Clidemia hirta (L.) D.Don
Medinilla heterophylla A.Gray
Melastoma denticulatum Labill.

MELIACEAE
Aglaia elegans Gillesp.
Dysoxylum gillespieanum A.C.Sm.
D. lenticillare Gillesp.
D. richii (A.Gray) C.DC.
Xylocarpus granatum Koenig

MIMOSACEAE
Acacia koa A.Gray
A. richii A.Gray
Mimosa pudica L.

MONIMIACEAE
Hedycarya dorstenioides A.Gray

MORACEAE
Artocarpus altilis (Parkinson) Fosberg
Ficus barclayana Miq.
F. benjaminia L.
F. pritchardii Seem.
F. storckii Seem.
F. vitiensis Seem.

MYRISTICACEAE
Myristica castaneifolia A.Gray
M. grandifolia A.DC.

MYRSINACEAE
Maesa insularis
Maesa tabacifolia Mez.
Rapanea myricifolia (A.Gray) Mez.

MYRTACEAE
Decaspermum vitiense (A.Gray) Niedenzu
Metrosideros collina (Forst.) A.Gray
Psidium guajava L.
Syzygium effusum (A.Gray) C.Muell.
S. gracilipes (A.Gray) Merr. & Perry
S. richii (A.Gray) Merr. & Perry

NYMPHACEAE
Nymphaea capensis Thunb.

OLEACEAE
Linociera vitiensis A.C.Sm.

ONAGRACEAE
Ludwigia octovalvis (Jacq.) Raven

OXALIDACEAE
Oxalis corniculata L.

PAPILIONACEAE
Derris trifoliata Lour.
Desmodium heterophyllum (Willd.) D.C.

PASSIFLORACEAE
Passiflora foetida L.

PIPERACEAE
Macropiper puberulum Benth.
Piper aduncum L.

PITTOSPORACEAE
Pittosporum pickeringii A.Gray
P. rhytidocarpum A.Gray

POLYGALACEAE
Polygala paniculata L.

POLYGONACEAE
Polygonum dichotomum Bl.

POTIALIACEAE
Fagraea vitiensis Gilg. & Benedict

PROTEACEAE
Turrillia ferruginea (A.C.Sm.) A.C.Sm.

RHAMNACEAE
Alphitonia zyzyphoides (Spreng.) A.Gray

RHIZOPHORACEAE
Brugiera gymnorhiza (L.) Lam.
Rhizophora samoensis (Hochr.) Salvoza
R. stylosa Griff.

ROSACEAE
Parinari insularum A.Gray

RUBIACEAE
Borreria laevis (Lam) Griseb.
Calycosia petiolata A.Gray
Gynochthodes ovalifolia (Valeton) Kanehira
Morinda citrifolia L.
Mussaenda raiateensis J.W.Moore
Neonauclea forsteri (Seem.) Merr.
Psychotria gibbsiae S.Moore
Randia vitiensis (Seem.) Fosberg
Sukunia pentagonioides (Seem.) A.C.Sm.
Timonius affinis A.Gray

SAPINDACEAE
Arytera brackenridgei (A.Gray) Radlk.
A. concolor (Gillesp.) A.C.Sm.
Cupaniopsis amoena A.C.Sm.
C. leptobotrys (A.Gray) Radlk.
Dodonea viscosa (L.) Jacq.
Elattostachys falcata (A.Gray) Radlk.

SAPOTACEAE
Palaquium fidjiense Pierre ex Dubard
P. hornei (Hartog ex Baker) Dubard

SCROPHULARIACEAE
Lindernia diffusa (L.) Wettst.

SOLANACEAE
Solanum nigrum L.
Solanum torvum Swartz

STERCULIACEAE
Firmiana diversifolia A.Gray
Heritiera ornithocephala Kosterm.
Sterculia dasphylla A.C.Sm.

S. vitiensis Seem.
Waltheria indica L.

STRYCHNACEAE
Neubergia alata (A.C.Sm.) A.C.Sm.
N. corynocarpa (A.Gray) Leenhouts

THYMELIACEAE
Phaleria glabra (Turrill) Domke

TILIACEAE
Trichospermum richii (A.Gray) Seem.

ULMACEAE
Gironniera celtidifolia Gaud.
Parasponia andersonii (Planch.) Planch.

URTICACEAE
Dendrocnide harveyi (Seem.) Chew
Elatostema insulare A.C.Sm.
Pipturus platyphyllus Wedd.

VERBENACEAE
Faradaya ovalifolia (A.Gray) Seem.
Premna taitensis Schauer.

APPENDIX B

RAW POLLEN COUNTS FOR ALL SURFACE AND FOSSIL SAMPLES

B.1: Forest Surface Sample Pollen Counts

Taxa	Sample Numbers																								
	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	T1	T2	T3	T4	LAKE	T8	T9	T10	T11	T12	T13	T14	T15
Acalypha	1		5	48	7	1		4	2					2	7	3	14	2	2			1		1	2
Agathis					1									1	1				1						
Alphitonia				4											1						1	3	1	2	
Antirrhea		1	2					1	2			1						1	2		3			1	
Apiaceae									1						2		1								1
Apocynaceae		6	2		1																			4	5
Arecaceae	67	30	16	10	21	3	2	3	11	88	23	38	22	26	24	11	2	4	11	15	26	29	18	7	16
Arytera comp.				1		2									1			2	1		1		3	4	
Ascarina					1	1					2	1	1		2		28								
Asteraceae (tubuliflorae)	7	51	27	2								2	1	1	1		1		1			3	2	1	7
Baccaurea				1						2							2				1		2	3	2
Balanops																	1								
Bischofia	2			2	1	2	2	5	2		4	3	2	17	11	2	4	7	1	3	2	1	3	1	1
Calophyllum				1	2	2				2		1		7		1		1	1		3	2		7	3
Calycosia											1				1										
Casuarina															3		1			2			1		
Celtis comp.					1			2	1								15			1		3	5		
Collospermum comp.	1	6	27	7	1	1			1													1	1		
Commersonia						2	80	26	16	5	5	3	2	3				3			1			1	
Cunoniaceae C2						1			1				1		1			1	1		1		2		
Cunoniaceae C3						2	2	6	1	1		2	1	1	1				1						
Dacrydium									2			1					1				3				
Dillenia			1										1		2			2							
Dysoxylum		1	2	1						2	1		1					1		1	2		2		1
Elaeocarpus	1		1	2	2	1	1	6	3		3			2	3	1	3				1			4	
Elattostachys			2		1																			3	3
Embelia			1				3	1	3					2	1		2		6					2	
Endospermum	1	7	12	19	12	5	1	1	1		1			4	3	1		2	1	4	1	72		10	73
Epacridaceae												1													
Euodia	1			1		3					3		1		2	5		1	1		8	2	1		1
Fagraea					1		1															1			
Freycinetia	2	11	54	37	75	120	18	55	57	67	46	45		22	8	35	7	5	80	30	29	7	65	47	31
Geniostoma				1				1													2			4	5
Glochidion		1								1									2			2			
Guioa														1											
Hedycarya																									1
Homalium	1				5	3	18	3		3	1		1	2	1	2	1		1			2			
Heritiera																	2								

Forest Surface Sample Pollen Counts cont'd

Taxa	DV1	DV3	DV4	DV5	DV6	DV7	DV8	Tom1	Tom2	Tom3	Tom4	Tom5	W1	W2	W3	W4	W5	W6	W7
Acalypha	1	2	5	1			4	2	1	4		5		2	4	4			3
Agathis	1								1		1	1		1		2		1	1
Alphitonia										1				1	2		3		
Antirrhea																			
Apiaceae							1			1	1								
Apocynaceae															1	1			1
Arecaceae	3	6	9		4	6	10	2		3	4	3	4	10	6	13	9		6
Arytera comp.																			
Ascarina								1	4										1
Asteraceae (tubuliflorae)	9					1	52		1	26		14	5	3	1		2	6	6
Baccaurea					1	1	1			2							1		2
Balanops									4	1				1		2	2		1
Bischofia		1			8		3	5	21	17	12	21	26	41	19	28	42	5	30
Calophyllum	5		3					5		4	5	3	2	1	3	1		4	2
Calycosia																			
Casuarina		1			1									1			1	1	5
Celtis comp.					6	3	9	1	4	3	4	3	42	25	8	5	16	3	10
Collospermum comp.																11	3	5	6
Commersonia					8					4			1	1	2		1	4	
Cunoniaceae C2'		1			1			1						1	4				
Cunoniaceae C3	14	72	79					136	10	3	5		1		1	3			
Dacrydium								1	5	3	1	3		9		4	2		6
Dillenia	7				4												1		3
Dysoxylum										3				1					
Elaeocarpus	1		3	2	3										3			2	1
Elattostachys											1	10		1					
Embelia							2	4	4	2	2	1		2	3	1	1	1	
Endospermum			2			2	6				1	3	1	2					1
Epacridaceae			1		4			1	5									1	
Euodia	2	1	1		1	34	1			21	5					1		1	
Fagraea																			
Freycinetia	1	56	55	10	4		3	13	18	26	27	5		5	46	28	12	7	7
Geniostoma	2		2			1											1	1	1
Glochidion							49	1			22							1	19
Guioa							2				8	1		1					
Hedycarya										2	1			4		2	2		
Homalium					1			1	3	2	6	4		2		5	7		2
Heritiera																			

Forest Surface Sample Pollen Counts cont'd

Taxa	Sample Numbers																								
	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	T1	T2	T3	T4	LAKE	T8	T9	T10	T11	T12	T13	T14	T15
Ilex					2	3	4	2	3	3	10	10	4	3	1		1			5	1	4		3	
Lantana									1													2			
Leguminosae			1				1					1		2		1				1	1			1	
Linocieria															1		2								1
Macaranga	5	60	6	2	20	15	35	12	16	14	59	16	13	15	18	3	10	24	10	7	14	8	16	48	8
Maesa		1	4		4			6	1						1					2		1	5	2	2
Mallotus							2		2		1			6			1								
Melastomataceae	2				6								1		1		2		6	1				6	
Melicope			1	1	3					2											1	6		3	
Melochia							1					2						1							
Metrosideros		1	11	2	4		5	1			1		2	2	2	1	5	17						3	8
Myristica		2																				1		1	
Myrtaceae		2	2	1	5	4	9	1	7		2	4		3	2	1	11		3	12	10	19	13	8	7
Neonauclea				27										2	1							3	5		
Omalanthus									3		1	2			1		5							1	1
Ophiorrhiza		1		1			1					1	1				1		3	4	4	1	8	3	1
Palaquium			4			1	1	1				1												1	
Pandanus						1		1						1	3	2	15								
Parinari			1																		1	2			
Pisonia																	1								
Planchonella		1	1					2										1							
Plerandra		1					1		2		3	5		3		1	3				7		2	2	
Poaceae	2	2		2	1				1	1		2	1	1	4	6	8		1				1		
Podocarpus	2			2	8	15	1	45	7	10	2	26	11	25	12	2	4	11	33	1	21	10	26	7	3
Polyscias					2	1	1	2	8														1		
Psychotria										2												1			
Rapanea			1					5	11	3	22	9	6	4			5		2	1	48	1	2	4	
Rhamnaceae undet.																		1			1	2	1		1
Rubiaceae undet.	1	1			3		1		1																
Rutaceae undet.	1																								
Scaevola											1	2			2		1				1	5	3	1	1
Schefflera									3	1				1			2								
Solanaceae			1		1		1							1			1	1						2	2
Streblus																									
Symplocos																	2	1		1					
Tapeinospermum																									
Turrillia													3								1				

Forest Surface Pollen Sample Pollen Counts cont'd

Taxa	Sample Numbers																		
	DV1	DV3	DV4	DV5	DV6	DV7	DV8	Tom1	Tom2	Tom3	Tom4	Tom5	W1	W2	W3	W4	W5	W6	W7
Ilex		2							1	4	3		1					1	1
Lantana																1			
Leguminosae							1			1	4		2		6				2
Linocieria	5		1								4			1		2			
Macaranga	31	8	6	1	5	1	7	2	10	5	2	21	6	9	9	5	4	70	1
Maesa		1							5			1		4	1		1	1	1
Mallotus	5				3		2			1					2				
Melastomataceae			1				1	2	4	4				1	11		10	11	2
Melicope		2	2			25	2							1	1				
Melochia					5			3		1	1	1		1					
Metrosideros											8								
Myristica																			
Myrtaceae	1		1				2	2	33	7	15	12	2	2	2	4	5	2	7
Neonauclea		1									1						1	1	
Omalanthus	2		1	2	24	108	7	1			4			1	2	1	2		2
Ophiorrhiza		2				1			3	5	4	4		1	4	2		2	1
Palaquium															1				
Pandanus		1												3		6	3		3
Parinari												1							
Pisonia														2					
Planchonella																	1		
Plerandra		14	2		1	1		1	18	11	19	3		1		1	3	4	1
Poaceae	5		1	2	12	1	2	3	4	1	1	3	85	22		30	24	2	25
Podocarpus	2	2		1	1			2	2	4	15	37	2	9	12	4	9	2	15
Polyscias										1								29	4
Psychotria										1									
Rapanea		6	7						1	1				4	1	2	3	1	5
Rhamnaceae undet.							1				1			2					
Rubiaceae undet.							3								1			1	
Rutaceae undet.																			
Scaevola			1		3		1		1		3	2		2	3		2	1	
Schefflera	3														1			5	
Solanaceae							2											5	1
Streblus																	1	1	
Symplocos									20			1		1	3	3			1
Tapeinospermum		1																	
Turrillia											2	1						1	1

Forest Surface Sample Pollen Counts cont'd

Taxa	Sample Numbers																								
	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	T1	T2	T3	T4	LAKE	T8	T9	T10	T11	T12	T13	T14	T15
Trema comp.																	2	3							
Urticaceae 1	3	18	12	19	8	1	7	6	25		8	17	24	40	30	23	31		6	7	8	2			
Urticaceae 2											1	2			1		15	22	1		1		3		9
Leguminosae 2			1	3	1	10	2	2	3								7		2	1	2		3	1	
Araliaceae																									
Nyctaginaceae																									
Cupaniopsis				1																		1			
Pittosporum				1																					
Leea																			1		1				
Cleistocalyx																					1				
Timonius			1														1						4	1	
Malvaceae																								1	
Claoxylon																									2
Tiliaceae																									2
Sterculiaceae undet.									4																
Dacrycarpus																									
Cyperaceae undet.	1									1			1		7		4		2				1		
Lepironia comp.												1		1	37	2	61	1							
Haloragis sim.						1												4							
Polygonum				1																					
Blechnum comp.		4	3	7	11	11	2		2			5		2	2	1		3	8	7	7		5	1	10
Cyatheaceae	26	21	168	48	64	66	21	27	45	31	28	68	36	41	104	54	5	176	26	25	163	33	128	128	210
Dicksonia	34	328	12	20				10	1							5		11	5						
Dicranopteris	5		2	1	1	3		1		1	2	9	8	4	24	8	1	23	3	26	75	16	158	37	10
Hymenophyllum		1				2	1	5	3	5	4	2		3		6			6	12	8		1		
Lycopodium cernuum		1										3	1	75	40	2	8	111	1		5		2		
Lycopodium squarrosum		1	2		3			1				4				4			5	2	1				
Lygodium	1	1		1	1					8		4	2										4	4	1
Polypodium		8	40	29	25	11	26	19	22	21	18	22	8	8	22	29	6	17	52	49	40	1644	41	20	154
Pteridium														2	28	3		5		1				1	
Sphaerostephanos			12									2									1				
Monoscabrate		30	32	38	20	29	4	4	2	3	3	9	3	22	27	9	3	28	28	1	38	2	23	27	32
Trilete undet.	48	144	73	10	44	33	12	19	25	29	17	31	10	35	60	54	2	82		42	51	22	49	19	288
Monolete undet.		34	15	17	21	16	3	2		6	8	6	4	6	5	11	3	14	10	14	11	9	10	8	9

Forest Surface Sample Pollen Counts cont'd

Taxa	Sample Numbers																		
	DV1	DV3	DV4	DV5	DV6	DV7	DV8	Tom1	Tom2	Tom3	Tom4	Tom5	W1	W2	W3	W4	W5	W6	W7
Trema comp.						5			8	2			6						
Urticaceae 1	41	18	20	18	95	6	16	3	9	2	4	27	3	6	3	9	12		7
Urticaceae 2						3	12			3	2	4		2		3	12	1	3
Leguminosae 2		2			1		1				1					4			
Araliaceae				1				1											
Nyctaginaceae	4																		
Cupaniopsis									1										
Pittosporum															1			3	1
Leea						1			5	6		1						8	1
Cleistocalyx																			
Timonius																			
Malvaceae																			
Claoxylon																			
Tiliaceae													1			2	1		
Sterculiaceae undet.																			
Dacrycarpus												2		3	1	1			3
Cyperaceae undet.	6	1	2					2		1	2		9	202	29	141	128	13	202
Lepironia comp.																			
Haloragis sim.																			2
Polygonum																			
Blechnum comp.	192			1	10	4	42	58	4	3	16	1	4	9	8	13	5	1	8
Cyatheaceae	15	166	111	6	86		310	45	36	10	36	3	17	145	17	100	11	13	84
Dicksonia											11	1	1	48	41	27	19	5	63
Dicranopteris	6		2	5		236	46	6	3	2	12	2	2	36	8	29	7	4	4
Hymenophyllum		2	10		4		27		1	1		1	4	6	1	2		3	3
Lycopodium cernuum								1						1	1			2	
Lycopodium squarrosum		2	1		1	1	1		1		2			1	1				1
Lygodium					1			5	1	1				2					
Polypodium	8	15	3	8	10	10	75	14	3	2	12	2	6	32	10	41	28	35	56
Pteridium					19						1			1			1		
Sphaerostephanos	1													3					
Monoscabrate	830	5	12			1	6				27	17		14	3	12	3	2	5
Trilete undet.	9	134	43	1	38		122		67	23	238	24	47	79	14	36	59	13	133
Monolete undet.	8	10	2		17	3	72	23	4	4	7	3	3	19	7	34	3	2	16

B.2: Coastal Surface Sample Pollen Counts

Taxa	Sample Numbers																	
	N1	N2	N3a	N3b	N4a	N4b	N5	N6	N7	M1	M2	M3	L1a	L1b	L2a	L2b	L3a	L3b
Acalypha	3		1	1	6	1			1		1							
Aglaia comp.								1										
Alphitonia							1											
Antirrhoea		2			5													
Apocynaceae										2								
Arecaceae	12	10	2	7	5	12	15	8	13		7		2	1			2	2
Asteraceae	2		3	3	1					1	4		1	3			1	1
Baccaurea	1	1		1	4													4
Balanops					1		6	4	6									
Bischofia	2	1	4	7	9	8	1	1	3	6	15		3				1	4
Calophyllum										1					1			
Calycosia						1												
Casuarina		3	7	6	14	4	12	7	3	1			2		1			1
Celtis comp.	7	2	10	2	13	8	8		4									
Clematis															1			
Commersonia					1						1							
Cruciferae											1							
Cunoniaceae	1																	1
Dacrydium				1		1	1								1			
Dillenia	2										1							
Dysoxylum		1							4	1								
Elaeocarpus			1	1	1		4	2	1		1						1	
Embelia		4		2			1	2	1	1								
Endospermum	1				1	1	1		15	1								1
Euphorbiaceae undet.	32																	
Fagraea				1					1		2							
Geniostoma																		1
Hedycarya			1															
Heritiera							1											
Homalium	1	1	1			2		1		5	2						1	1
Ilex	1	1		1		2		1	5	1								
Ixora									1									
Leguminosae	2	9	5	2	5	1	7	1	4	2								
Liliaceae											1							
Macaranga	6	5	5	5	1	2	3	4	5	2	2		2					
Maesa				1														
Malvaceae		1																
Melastomataceae	3	10	1	2	5		3	1	5									
Melicope					2													

Coastal Surface Sample Pollen Counts cont'd

	Sample Numbers																	
Taxa	N1	N2	N3a	N3b	N4a	N4b	N5	N6	N7	M1	M2	M3	L1a	L1b	L2a	L2b	L3a	L3b
Metrosideros comp.							1											
Myristica						1	1		2									
Myrtaceae	2	1			2		7	4	17	1	1		1					
Psidium comp.			1			3	12	19	18	2								
Neonauclea			1		1					1								
Omalanthus	3		2	5	5	2	2	6	3		3		1				1	
Ophiorrhiza									2									
Palaquium							1											
Pinus													15	1	15	4	10	6
Pisonia																	1	
Pittosporum										1								
Planchonella	1				1	6			1	1								
Plerandra		1	3	1			1			2								
Poaceae	12	8	12	53	18	2	9	1	4	16			17	3	20	8	11	20
Podocarpus	1				1	1		1									1	
Polyscias				2			1											
Rapanea	1	3	5	2		2	13	4	4								1	
Rhamnaceae undet.									2									
Rubiaceae	1				2	1		1		5						2		
Rosaceae									3									
Sapindaceae undet.				2									1					
Scaevola				1						1								
Symplocos																		1
Tiliaceae								1	2									
Trema comp.	7					1		1	1	1			2				2	1
Urticaceae 1	8	1		4	6		2	4	1	2	4							
Urticaceae 2	6			2	3	7			2	5								
Euodia	2																	
Collospermum	7																	

B.3: Lake Tagimaucia Pollen Counts

	Sample Depths (cm)																								
Taxa	20	40	60	80	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600
Arecaceae		3	2	2	4	6	10	1	4	7	5	3	1	4	21	20	11	5	4	12	11	18	7	32	22
Ascarina	6	16	15	13	26	11		5	23	25	14	17	15	12	4	9	7	5	5	7	15	12	17	11	5
Balanops								2	8	21	33	16	11	7	13	8	15	33	17	22	15	29	15	15	24
Cunoniaceae C2	2	2	2							3	1	2	2	3		2	1			2	1	4	3	6	6
Cunoniaceae C3	2	1		2		3		6	6	4	4	7	8	6	11	7	3	10	10	7	5	15	4	3	3
Macaranga	32	15	24	10	26	21	15	12	8	10	9	12	6	10	4	5	7	5	1	4	6	7	6	7	2
Metrosideros	5	6	3			4	4	6	3	3	3	7	1	5	3	6	7	6	2	5	1	2	1		
Myrtaceae 1	2	1	1		3	1	2	15	8	10	14	11	10	10	18	24	28	34	32	13	25	9	22	9	22
Myrtaceae 2							4	5	3	8	10	15	36	6	10	12	14	12	43	33	42	18	36	26	32
Myrtaceae 3					1		5		1	3	9	4	7	3	2	9	13	9	7	3	5		10	2	17
Myrtaceae 4										1	2	10	2				3	7							
Cleistocalyx						1		5			2	2	4	3	3				2	5	1	14	8	1	1
Rapanea	3		1		5	4	3		28	21	24	24	6	36	23	17	16	12	6	6	3	5	12	5	3
Ulmaceae	26	10	16	22	53	32	20	23	6	7	3	2	2	9	8	2				3			2	3	
Urticaceae 1	34	65	68	66	17	26	26	59	24	6	4	13	29	20	11	6	2	7	2	4	5	8	8	4	3
Urticaceae 2	45	34	20	37	1	14	25	12	6	1		2		1	1			1		1					
Acalypha	13	8	6	5	13	11	11	11	1		2	1		1	1							1			
Bischofia	3	7	4	4	5	3	8		6	3	2	2	2	2	1	1	2			1		2	4	3	
Calophyllum	1		1		4	1	3	1	1	3	2	4	2	7	7		1	3	5	9	5	4	5	10	8
Coprosma									8									1							
Dacrydium							1																		
Dysoxylum	3	1	1		1	1						1		4	1	3	1		1	3					
Elaeocarpus		1	4	3	1		1		5	6	8	6	6	10	2	5	2	5	4	1	2	3	4	2	6
Embelia	1							2	3	1	7	6	6	1	2	2		3	6	1	4	1		4	1
Euodia						2								1	1				1	1	1	1			2
Ilex	1		2			3	2		5	3	4	11	5	3	3	8	7	4	2	3		2	1	1	2
Maesa		1				1	1	1	1		2	6		3	2		4	1	3		2	1		2	1
Omalanthus	1		6	7	17	28	19	7	4	7	3	5	2	4	9	3	2	1	3	6	7	7	4	5	3
Palaquium	1						2							1	1	5		1	1	5	1	2	2	3	14
Planchonella					1									3				1	4	9	3	1			8
Plerandra	2			1	2	2	2	2	2	5	1	3		7	5	3	7	3	9	12	10	5	2	4	5
Podocarpus	1	2	1	5	3	3	2	2	9	2	1		1		1	4	8	3	6	3	3	3	3	3	4
Symplocos						1			3	7	11	7		1	4	4	11	7	3	3	2		6	1	2
Turrillia	1							1					1					1		1	3	1		1	

Lake Tagimaucia Pollen Counts cont'd

Taxa	Sample Depths (cm)																								
	620	640	660	680	700	720	740	760	780	800	820	840	860	880	900	920	940	960	980	1000	1020	1040	1060	1080	1100
Arecaceae	14	11	19	7	20	12	14	5	23	20	28	71	58	75	56	67	85	19	26	23	35	29	16	16	6
Ascarina	8	15	6	8	8	16	6	8	15	21	34	19	11	10	12	14	11	15	36	48	50	36	40	45	45
Balanops	3	5	37	28	16	17	87	91	30	14	16	6	20	22	20	24	14	2	1		3	5	11	41	41
Cunoniaceae C2	2	1	1	4	1	1	2	1	2	1	1					1			3	5	2	8	10	3	10
Cunoniaceae C3	1	11	3	6	2	2	4	5	6	3	5		6		3	4		2	4	9	3	15	7	4	9
Macaranga	7	11	2	2	8	8	2	3	7	3	8	13	10	5	8	6	6	9	7	6	1	3	7	4	4
Metrosideros	6		4	4	1	1	4		1	2														1	1
Myrtaceae 1	16	10	10	28	15	18	4	11	12	18	7	7	2		3	5	3	3	3	6	2	3	2	11	4
Myrtaceae 2	27	17	42	39	34	30	20	7	19	19	10	8	11	6	5	7	8	8	16	6	7	4	8	2	16
Myrtaceae 3	9	3	11	4	7	12	3	6	4		3	2	3	1		2	2	1	3		2	3	4	1	4
Myrtaceae 4																									
Cleistocalyx			2	3						2								3				1			
Rapanea	2	11	11	23	10	10	5	9	4	8	11	5	7	5	6	11	11	1	3	10	6	9	6	8	4
Ulmaceae	1									2	1		1	2	4	4	2	6	2	3	2		1		
Urticaceae 1	6					1	1		7	2	6	2	4	8	12	4	13	65	30	7	8		16	2	3
Urticaceae 2	2		2	1		1			1			2			4	3	2	12	5	1	3	2	4	4	4
Acalypha										1				1		2		2							
Bischofia	2		1		2	2	2	3	3	1		4	4	2	2	4	3	7	1	3	2	4	4	3	4
Calophyllum	7	8	8	2	13	5	3		4	3	1	6	4	3	3	4	2	2	1	5	1		2		
Coprosma	1									3	2					1				2	2	2		6	4
Dacrydium																									
Dysoxylum						1		1			2				1						1				
Elaeocarpus	4	16	4	8		1	4	2	5	2	6		4	2	4	1	1	5	8	6	6	5	4	1	3
Embelia	5	9	1	2	5	1		1		1	1	3	2	1	6	2	2	3	3	7	1	3	4		3
Euodia	7	3	1	3		3	1		4	2	2	3	4	1		1	1	1	1			8		5	
Ilex	5	3	6	3	1	3	3	7	5	5	5	5	2	1	2	1			1	3	1	6	2	1	1
Maesa	2	6			2	1		4	3	1	1		1		6	3	2		2	2	2		1	1	1
Omalanthus	5	6	6	4	5	3	5	7	7	3	12	10	2	4	6	3	12	4	3	2	3	5	3		
Palaquium	2	2			1	1				1		1		1	1	1							1	1	
Planchonella	1				1						5	1		1	2				1		1				
Plerandra	13	9	1	7	7	10	2	5	1	5	5	5	2	1	4	7	3	3	4	5	6	5		4	2
Podocarpus	18	9	6	4	11	10	18		6	25	6	5	5	5	6	5	2	3	2	24	17	15	5	1	5
Symplocos	8	3		5		5	2	1	5	7	2	4	2	3	2		2		2	7	2	5	5	4	2
Turrillia	3	1	2		1	3		1						1		1						1		1	1

Lake Tagimaucia Pollen Counts cont'd

Taxa	Sample Depths (cm)										
	1120	1140	1160	1180	1200	1220	1240	1260	1280	1300	1320
Arecaceae	7	13	6	27	38	8	7	4	8	4	2
Ascarina	43	18	47	37	38	54	44	26	42	50	40
Balanops	57	40	17	14	14	10	14	8	14	17	9
Cunoniaceae C2	5	7	14	1	2	3	1	1			1
Cunoniaceae C3	7	8	11	7	10	8	7	14	8	6	4
Macaranga	5		6	10	3	2	3	7	1	1	
Metrosideros		1									
Myrtaceae 1	7	3	15	3	5	1	4	6	1	1	3
Myrtaceae 2	9	10	8	8	3	3		1	4	2	1
Myrtaceae 3		1			1				1	2	
Myrtaceae 4											
Cleistocalyx											
Rapanea	9	6	7	10	12	5	6	9	9	2	2
Ulmaceae			2	1	2	3	3	1	2		
Urticaceae 1	5	15	4	3	7	11	8	10	10	3	5
Urticaceae 2	1	2	3	6	2	5	5	4	4	4	1
Acalypha		1				3	1		1		
Bischofia	3	12	1	9	7	1	13	5	4	3	1
Calophyllum		1	2	1							
Coprosma				1	3	2					
Dacrydium	1	6	3	2	5	1	2	3	6	7	7
Dysoxylum	1							1			
Elaeocarpus	5	3	3			12	3	7	2	1	1
Embelia	5		5	9	4		1	10	3	2	
Euodia	1			7		1	3	3	1		
Ilex	2		3	1	4			1		1	
Maesa	1		1	1	2	3	1	3	3	2	
Omalanthus	1	4			3	2					1
Palaquium				2							
Planchonella		1									
Plerandra	4	3	7	1	3				1	14	
Pdodcarpus	4	8	7	6	3	27	38	64	55	69	106
Symplocos	5	1		8	5	4	2		3		2
Turrillia		1	2	1							

Lake Tagimaucia Pollen Counts cont'd

Taxa	Sample Depths (cm)																							
	20	40	60	80	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600
Acronychia comp.	1															2				1					
Agathis		1	1					1		2				1		1	1	2					1		
Aleurites			2	1																					
Alphitonia		2		1																					
Amaranthaceae																									
Antirrhoea								1	1	2		1		2			1	4	2	2	4		2	2	4
Apiaceae	2																				1				
Araliaceae undet.										4		2								1			2		2
Ardisia													3					2						3	
Arytera	1																								
Asteraceae	2				1			1	1																
Baccaurea		1		2			2					1				1									
Calycosia					1							4					1							1	1
Casuarinaceae	1	2	1	1	1	3		3	3	1		1													1
Claoxylon								2				1		1											
Clematis				5															1						
Collospermum					1																	1			
Commersonia								2								1						1		1	
Dillenia										1		1	1		1	1	2					2	1		
Dodonea				1																					
Dolicholobium								2																	
Elattostachys																								2	
Endospermum	1		4	3			2				1			2		1	1						1	1	1
Epacridaceae										1	2	2	3	1	1	1	2		1	1					2
Euphorbiaceae undet.				1																					
Exocarpus																						3			
Fagraea										1								1							
Garcinia				1																					
Beniostoma	2					2				2		1						2					1		
Guioa						1	1			1														1	1
Heritiera											1											1			
Homalium	1			1	1	2	1	1			1	2	1	1		5		1	1						
Ixora												1													
Jasminim						1																			
Leea																									
Glochidion					5		1																		

Lake Tagimaucia Pollen Counts cont'd

Taxa	620	640	660	680	700	720	740	760	780	800	820	840	860	880	900	920	940	960	980	1000	1020	1040	1060	1080	1100
	Sample Depths (cm)																								
Acronychia comp.																									
Agathis										1													1		
Aleurites																									
Alphitonia		1			3			2	1		2							2		1					
Amaranthaceae																									
Antirrhoea			1		1	3			1	3		2	1		1	1	1								
Apiaceae															1										
Araliaceae undet.	1			1	3						1														
Ardisia															1										
Arytera																								2	
Asteraceae																									
Baccaurea																				1					
Calycosia			1																1		1		1	1	
Casuarinaceae			1			1			2		2	1	1	2	1	1	1	2				2			
Claoxylon																									
Clematis																									
Collospermum									1																
Commersonia																					2	1	9		
Dillenia	1		1			1	1		2	2				1	2			1		1	4		2	3	1
Dodonea																									
Dolicholobium																									
Elattostachys																									
Endospermum			2						1	1				1	1							1	1	1	
Epacridaceae		1	1		1			1						1				2	2						
Euphorbiaceae undet.																								1	
Exocarpus																									
Fagraea																									
Garcinia																									
Geniostoma			2											1							3	3		1	
Guioa							1																		
Geritiera																									
Homalium	1	1	1	1	2	1		1		2					1	6	2	1		2	4	5	3	1	
Ixora																									
Jasminum																									
Leea												3				1			2						
Glochidion																									

Lake Tagimaucia Pollen Counts cont'd

Taxa	Sample Numbers (cm) 1120	1140	1160	1180	1200	1220	1240	1260	1280	1300	1320
Acronychia comp.											
Agathis		1				3	4	2	3	2	
Aleurites											
Alphitonia									1		
Amaranthaceae				2					1		
Antirrhoea					1						
Apiaceae				1							1
Araliaceae undet.											
Ardisia											
Arytera											
Asteraceae											
Baccaurea					1		2				
Calycosia	1						1	1		1	1
Casuarinaceae		2							3		1
Claoxylon											
Clematis											
Collospermum											
Commersonia				1	3	2					
Dillenia		1		2	1		2	1		1	1
Dodonea											
Dolicholobium											
Elattostachys							1		1		
Endospermum				1	2	1					
Epacridaceae								1			
Euphorbiaceae undet.											
Exocarpus											
Fagraea											
Garcinia											
Geniostoma					1		2			1	2
Guioa											1
Heritiera										1	
Homalium			2			1	1		1		
Ixora											
Jasminum											
Leea	1					1	5	1	1	3	1
Glochidion.											

Lake Tagimaucia Pollen Counts cont'd

Taxa	Sample Depths (cm)																								
	20	40	60	80	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600
Leguminosae 1		1			2				1	2	1		1	1	1	3	2	1		2	2	5		1	
Leguminosae 2		1	3	1			1	4	10	7	5	18	16	9	16	9	7	6	3	2	4	1	5	13	
Linocieria										1	2	2		1	2			1			1	2			
Mallotus	1		2	1	4	3	4	2	2		1		1	1				1	2						
Malvaceae			2																						
Medinilla comp.	1		2													1									
Melastomataceae					1		1	1	1				2			5	5	2		2		5	1	1	4
Melicope									3													1			
Melochia			1							1			1	1					1		1	1	1		
Mussaenda																					1				
Myristica																									
Neonauclea comp.	1		1		1			1			1	1	1												
Neubergia																	1								
Ophiorrhiza												3	1	1	1									2	
Parasponia	22																								
Parinari comp.										2		1			1	1	1	2	2	2	1		3	4	2
Pemphis comp.																								1	
Phaleria																									
Pisonia comp.													1												
Pittosporum																									
Poaceae	3	3	3	2	1	2	4	1	7	2					1										
Polygala				1																					
Polyscias																									
Psychotria		1				2	1		1				1			2				1					
Randia					1																				
Rhamnaceae undet.								2									1	1						2	
Rubiaceae undet.																									
Rubus comp.				1																				1	
Rutaceae undet.	1					2					2	1					1	3							
Saurauia												1													
Scaevola comp.	1				3	2	3			1	1		2	2	2					1	4				
Schefflera comp.					2	2			2	3	2			2					4		3	5			
Solanaceae					4										1									1	
Streblus																									
Tapeinospermum												1													
Timonius							1					1					2		2						
Trema comp.																									
Quintinia comp.																								1	
Rosaceae udet.																									

Lake Tagimaucia Pollen Counts cont'd

Taxa	Sample Depths (cm)																								
	620	640	660	680	700	720	740	760	780	800	820	840	860	880	900	920	940	960	980	1000	1020	1040	1060	1080	1100
Leguminosae 1	1	8		1		1		2	1	6			6		3		1	1	4	1	1	1	1	3	2
Leguminosae 2	1	8	4	5	6	3	3	1	8	2	3	5	6				3	8	14		1	4	4	4	7
Linocieria																							1		1
Mallotus	2	2														2							1	1	
Malvaceae																									
Medinilla comp.																									
Melastomataceae	1			1			1	2			1						1						1		
Melicope						1						1	2	2									2	1	
Melochia	1	1			2																		1		
Mussaenda																									
Myrtistica									1																
Neonauclea comp.						3	1						1	1	1	2		1							
Neubergia																									
Ophiorrhiza					3				2		1	1	3									1			
Parasponia																									
Parinari comp.		1				5	1	1	1	1	3				1					1	2				
Pemphis comp.																									
Phaleria																									
Pisonia comp.						1																2			
Pittosporum																						1			
Poaceae									1	5	2	1			1		1		1		2		1		3
Polygala																									
Polyscias									1						2						3				
Psychotria		1		2	2				3			1					2		1				1		2
Randia																					1				
Rhamnaceae undet.		3						1																	
Rubiaceae undet.																				1				1	
Rubus comp.						1										1						1			
Rutaceae undet.																									
Saurauia																									
Scaevola comp.					5	1	1				5	1	2	1		1	3	2	4		1	2		2	
Schefflera comp.	1	1						1												1					
Solanaceae				1									1			2		2	2				2		
Streblus																									
Tapeinospermum																									
Timonius	3													1											
Trema comp.																									
Quintinia comp.									4			2	11	1		1		1	4	2	2	7	5	6	7
Rosaceae undet.					1																				

Lake Tagimaucia Pollen Counts cont'd

Taxa	Sample Depths (cm) 1120	1140	1160	1180	1200	1220	1240	1260	1280	1300	1320
Leguminosae 1	4	3	3	1	5		1				1
Leguminosae 2	5	6	8	7	4		1				
Linocieria											
Mallotus						3					1
Malvaceae											
Medinilla comp.											
Melastomataceae				1							
Melicope	4		4	3		1	1				1
Melochia											
Mussaenda											
Myristica											
Neonauclea comp.											
Neubergia											
Ophiorrhiza			3			1	1			1	
Parasponia											
Parinari comp.		1				1					
Pemphis comp.											
Phaleria	1										
Pisonia comp.											
Pittosporum											
Poaceae		2	2	2	5	8	6	1	1	3	
Polygala											
Polyscias											
Psychotria	1	1									
Randia											
Rhamnaceae undet.											
Rubiaceae undet.							1				
Rubus comp.			3	2	1						
Rutaceae undet.					1						
Saurauia											
Scaevola comp.				2	1			1			
Schefflera comp.											
Solanaceae						1					
Streblus							2				
Tapeinospermum	1	1					1		2		
Timonius											
Trema comp.											
Quintinia comp.	1	6	4		3	5	1		1		1
Rosaceae undet.											

Lake Tagimaucia Pollen Counts cont'd

Taxa	Sample Depths (cm)																								
	20	40	60	80	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600
Freycinetia	2						5	6	39	33	15	22	12	15	30	18	6	9	11	4	13	15	13	16	20
Pandanus	2	2	2	3	1	2	2	20	366	768	381	219	151	330	485	480	240	215	164	83	164	86	98	105	165
Haloragis sim.			1		2				7	12	2	4		51	163	16	3	14	4	3	1	2	6	1	5
Lepironia comp.		3	2	19	23	517	388	121		4	1			3		1				18	1	8	3		3
Eleocharis comp.	1			2	14		5	49	2					3					1						
Cyperaceae 1				1																					
Polygonum	2	13	1																						
Potamogeton comp.																									
Blechnum comp.	6	13	7	14	8	12	7	13	4	7	8	4	3	1	2	13	6		2	3	3	5		10	3
Cyatheaceae	19	22	13	10	21	26	29	9	10	20	18	15	8	8	6	24	14	16	55	28	54	28	6	32	39
Dicksonia	22	7	15	8	21	1	3				2		1			1			3	7		7	2		3
Dicranopteris	44	33	22	47	52	54	36	30	24	20	10	20	8	24	10	17	11	6	11	11	14	21	2	9	6
Hymenophyllum	1	1	1			2	1	4	2	1	1	3	1	1	1	1			1	1	3	3	3	1	7
Lycopodium	10	1	2	2	34	6	4	9	127	37	19	7	5	4	5	11	3	7	3	5	4		7	2	11
Lygodium		1			5		1	1	3			1		2				1			1				
Polypodium	12	10	6	11	13	7	9	6	11	7	6	8		1	6	77	2	3	6	3	13	9	4	3	9
Pteridaceae							4									1									
Sphaerostephanos					1																				
Monolete A		9	1	4		5		9	1	3	3	1		2	1	4	2		1	1		3		1	1
Monolete B	2				10		1										3								
Trilete undet.	7	4	6	3		6	2		5		4	2		4								1			

Lake Tagimaucia Pollen Counts cont'd

Taxa	Sample Depths (cm)																								
	620	640	660	680	700	720	740	760	780	800	820	840	860	880	900	920	940	960	980	1000	1020	1040	1060	1080	1100
Freycinetia	9	27	21	18	24	14	3	3	1	4	15	8	3	5	7	5	6	6	3	27	24	152	54	9	4
Pandanus	125	445	101	115	147	128	29	34	90	136	151	54	25	29	915	65	91	20	106	164	152	53	14	3	
Haloragis sim.	1	2	3	3		3	7		2	1	2	1	3	3		2	2				1	9		1	1
Lepironia comp.	1	1	3	1			1	1	38	67	42	33	18	14	7	3	36	33	7	2	2	6	6	3	
Eleocharis comp.								3																	
Cyperaceae 1							5	1	4	26					7	4	21	5			2				
Polygonum																									
Potamogeton comp.											1														
Blechnum	6	7	11	5	12	22	8	7	16	13	1	6	9	7	9	3	5	4		6	2	5	4	1	
Cyatheaceae	49	100	81	75	150	340	36	73	69	88	152	47	33	24	22	21	16	17	74	28	36	35	17	9	24
Dicksonia	1	2						4						1		4		2							
Dicranopteris	11	14	19	9	28	31	7	17	19	20	25	10	2	5	4	8	4	13	23	12	7	9	5	2	1
Hymenophyllum	4	6	4	3	4	3	2	3	3	2		2	1	1	1		1	1	1		3				
Lycopodium	7	2	6	2	6	10	1	11	6	12	27	54	44	8	14	121	2	2	4	18	31	70	35	27	8
Lygodium		1	3			2			1			1	1	4		1			2			1	1	1	
Polypodium	4	6	4	3	4	3	2	3	3	2		2	1	1	1		1	1	1		3				
Pteridaceae											1														
Sphaerostephanos																									
Monolete A	1	1	1		2	3		1	3	4			3	1	3		5	4		2				2	
Monolete B		2	1									1					1	1	1		3	3			
Trilete undet.	3										3														

Lake Tagimaucia Pollen Counts cont'd

Taxa	Sample Depths (cm)										
	1120	1140	1160	1180	1200	1220	1240	1260	1280	1300	1320
Freycinetia	15	36	15	140	117	11	8	11	7	3	7
Pandanus		1		12	105		1	2	1		1
Haloragis sim.	1			1	2			1			
Lepironia comp.	2	2	4	1						1	
Eleocharis comp.											
Cyperaceae 1						3				3	
Polygonum											
Potamogeton comp.											
Blechnum		2	2	1	6	13	8	5	10	9	1
Cyatheaceae	10	41	56	40	36	81	46	14	33	41	21
Dicksonia											
Dicranopteris	1	6		7	10	4	2		1		2
Hymenophyllum	3	2	1	1		8	3	1	1	5	2
Lycopodium	2	31	5	51	50	10	10	396	16	17	7
Lygodium										2	1
Polypodium	2	1		2		2	1		1		
Pteridaceae											
Sphaerostephanos											
Monolete A'					1						
Monolete B				5		1	1		2	1	
Trilete undet.											

B.4: Nadrau Swamp Pollen Counts

Taxa	Sample Depths (cm)																				
	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
Arecaceae	22	12	15	8	12	1	7		4	3	1	1	1	8	1	4	2	1	10	4	
Ascarina		1	2	1		1		2	2	1	1	1			1	1	2		1		1
Balanops						1				1				2		1					
Bischofia	6	9	11	11	3	9	12	8	4	5	5	6	7	10	10	18	12	12	11	4	9
Cunoniaceae C2							1	2	1				1				1				
Cunoniaceae C3				4			1		1			1									
Dacrydium		4		1	1	3	3	2	2	7	2			1	3	1		2			
Podocarpus	1															1	1			2	
Elaeocarpus			2		2									1							
Ilex							1				1					1					
Macaranga	3	9	3	3		1	4	3	5	2	4	4	4	5	6	3	4	1		1	
Metrosideros comp.		2																			
Myrtaceae 1		2	1	2	1	1									1			1			1
Myrtaceae 2																					
Myrtaceae 3						1		1						1							
Myrtaceae 4																					
Cleistocalyx																					
Omalanthus	5	2	9	8	12	7	2	6	19	12	4	10	3	7	5	7	5	1	5	4	2
Parasponia/Celtis	15			28	14	42	34	43	30	22	26	21	16	35	48	35	33	46	46	29	35
Trema comp.		4	19	1	12	3	4	3		2				7	7	10		8	5	22	3
Urticaceae 1		18	36	47	60	28	53	9	44		59	22	40	1	20	1	43	31	14	26	13
Urticaceae 2		14	10	10	6	4	3	17	7	16	23	6	6	9	11	6	25	1	8	8	16
Poaceae	92	38	46	75	52	70	53	75	60	60	24	102	102	83	70	72	57	67	78	90	100
Asteraceae (tubuliflorae)	43	57	14	2	2	3	5	3	3	11	5	4	5	4	3	8	1	5	6	3	6
Acalypha		1	1	1	3	3		3	1	1		2	2	1	1	4	4		7	1	2
Calophyllum	1	3						1		2											
Coprosma			1	2				1	2	3		1	3			3	1	1	1	2	1
Plerandra		2	2									1				1					
Rapanea	1	1	1		1	3		2	2	3	1	2		3		3		1		1	
Scaevola comp.			3				1				1									1	1
Symplocos							1									2					
Leguminasae												1									
Quininia comp.							1					2									2
Acronychia comp.													1								
Agathis								1			1			1							
Alphitonia	1					2	1									1					
Annonaceae						1															
Araliaceae undet.			1																		
Ardisia											1										
Arytera																					

Nadrau Pollen Counts Cont'd

Taxa	420	440	460	480	500	520	540	560	580	600
Arecaceae	4	1		2	4	2	2	2	5	10
Ascarina		1				2				1
Balanops						1	1	1	2	
Bischofia	5	8	13	4	9	3	2	3	2	3
Cunoniaceae C2				2	1		1	2		7
Cunoniaceae C3						2	7	3	12	7
Dacrydium		1	1		1	24	12	16	14	8
Podocarpus						4	2	2	3	7
Elaeocarpus	1					3	13	1	4	
Ilex				2				4	12	6
Macaranga			2	1	6	14	6	5	7	
Metrosideros comp.										
Myrtaceae 1	1					7	3	5		3
Myrtaceae 2										
Myrtaceae 3	1				4	11	6	11	7	14
Myrtaceae 4				4	2	4	15	5	16	9
Omalanthus	3	1	3	2	6	6	3	1		
Parasponia/Celtis	34	26	16	26	3	7	8		4	1
Trema comp.	15	7	14				11	4	5	
Urticaceae 1	12	10	1	26		15	12	9	14	4
Urticaceae 2	16	16	14	28	13	16	11		2	7
Poaceae	100	119	116	83	107	13	7	2	2	
Asteraceae (tubuliflorae)								1		
Cleistocalyx							1		6	
Acalypha		6	6	7	5	6				2
Calophyllum				1		2	11	34	20	16
Coprosma		1	1	1	10	1		1		
Plerandra						7	6	1	5	17
Rapanea	1		4	2	1	2	2	1	1	1
Scaevola comp.							1			3
Symplocos								2		
Leguminosae		1				2	4	3	3	3
Quintinia comp.				3	5	3	4	4		9
Acronychia comp.						1			1	
Agathis			1		3			1		
Alphitonia						1		1		1
Annonaceae						3				1
Araliaceae undet.					1					
Ardisia								1	1	
Arytera							3		3	1

Nadrau Swamp Pollen Counts Cont'd

Taxa	Sample Depths (cm)																				
	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
Baccaurea		3	2		2		1				2				2	2	1	2			
Calycosia																					
Casuarina										1	1		2	1					2	1	
Chenopodiaceae							1														
Claoxylon	2									1				1							
Clidemia comp.		1																			
Collospermum																					1
Cupaniopsis comp.		1																			
Dacrycarpus																					
Dillenia			1									1			1			1			
Dodonea			1		3								2								
Dolicholobium																					
Dysoxylum	1	1	1	2				1													
Elattostachys		1																			
Embelia		2	2	1			1		2			2								1	1
Endospermum	1							2				1				2					
Euodia		1	1		1										1	1					
Fagraea			1										1								
Geniostoma					1																
Glochidion			2																		
Guioa																					
Homalium	5		4	3	3	7	6	4	8	7	7	8	2	4	1	2		3	2	4	
Leea comp.																					
Leguminosae 2		2	1	1						1				1			1	3	2	1	
Linociera													2	1							
Maesa			2					1	1												
Mallotus		1	2			3	2	1		1			1		1	1	1				
Medinilla comp.		2																			
Melastomataceae			1	1	6	1		4		3	18	2		4	4	4	5	12	1		4
Melicope		1																			
Mussaenda																					
Myristica						1						1		1	1	1					
Neonauclea		1																			
Ludwigia		3																			
Ophiorrhiza			1										1								
Pandanus									1												
Parinari comp.						1															
Phaleria																					
Psychotria	1									2		1		2							

Nadrau Swamp Pollen Counts cont'd

Taxa	420	440	460	480	500	520	540	560	580	600
Baccaurea			1	1	1		1			
Calycosia						1	1	1		
Casuarina	1		2							
Chenopodiaceae										
Claoxylon										
Clidemia comp.										
Collospermum									1	6
Cupaniopsis comp.										
Dacrycarpus	1				1	3		7		2
Dillenia										
Dodonea					1		1		1	
Dolicholobium									1	
Dysoxylum						1		1	1	1
Elattostachys			1							
Embelia					1	4	6	1	2	3
Endospermum			1			5				1
Euodia								2	1	
Fagraea					1					
Geniostoma							2	1		
Glochidion										
Guioa			1		2	2		4		
Homalium			1		1		5		2	2
Leea comp.							1		1	
Leguminosae 2			1		1	3	1		4	
Linociera						1				
Maesa						1	5			
Mallotus	2				2	1		2		
Medinilla comp.						2				
Melastomataceae	1					2	2	2	7	1
Melicope							1		2	2
Mussaenda						1				
Myristica						1				
Neonauclea					3	1		2		
Ludwigia										
Ophiorrhiza							2			
Pandanus						6	9	45	24	36
Parinari comp.			1				4	1	1	3
Phaleria									1	
Psychotria				1		1				

Nadrau Swamp Pollen Counts cont'd

Taxa	Sample Depths (cm)																				
	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
Rhamnaceae undet.			1											1							
Rosaceae					1				1		3					1		1			
Rubiaceae undet.					1		1								2		1				
Rutaceae undet.																					
Tapeinospermum																					
Turrillia																					
Freycinetia							1														
Pisonia comp.								1													
Flacourtiaceae undet.								1													
Apiaceae										1											
Pittosporum comp.														1							
Polyscias comp.														1							
Clematis																1			1		
Rubus comp.																					
Streblus comp.																					
Melochia comp.																					
Solanaceae																					
Shefflera comp.																					
Cyperaceae 1	220	109	260	313	25	17	48	35	44	2	15	2		1	2	1		6	2	9	18
Cyperaceae 2		68												4			6	3	3		
Cyperaceae 3			93	26																	
Eleocharis comp.		55	112	27	35	66	43	20	28	7	75	3	6	1	13		5	1		18	20
Lepironia comp.			3																	16	
Haloragis sim.			1																		
Potamogeton comp.				5							1										
Anthoceros				5		1		1	3	6		9						26	6	2	10
Blechnum comp.	4	25	24	40	25	60	60	123	37	45	44	26	16	86	410	553	238	210	210	32	126
Cyatheaceae	6	7	14		6	29	10	15	18	31	6	12	8	14	11	17	15	9	11	8	17
Dicksonia		3									2									2	
Dicranopteris	32	73	67	69	31	23	24	31	45	23	31	18	5	10	21	36	24	11	21	13	10
Hymenophyllum			5		1		1	1						2	2		6	1	1	1	1
Lygodium			1	4	1	3	4	7	1	7	1			2	2	4		6	4	2	1
Lycopodium	8	4	4	2	1	1	7	7	92	208	67	98	137	707	440	992	363	238	372	36	85
Polypodium	6	6	4	6	1	1	6	3		2	1	11	4	11	11	5	4	3	5		7
Pteridium					2	1			2	1		2		3			3		5		
Stenochlaena comp.									1					2							
Monolete A	57	173	376	148	68	105	17	38	28	37	48	4	11	66	5	4	9	2	9	2	41
Monolete B	4	7	3	4	6	3	2	6	2	4	3		1	14	9	8	2	4	10	9	8

Nadrau Swamp Pollen Counts cont'd

Taxa	Sample Depths (cm) 420	440	460	480	500	520	540	560	580	600
Rhamnaceae undet.			1	1						
Rosaceae									1	
Rubiaceae undet.									1	2
Rutaceae undet.				1						1
Tapeinospermum						1	1			3
Turrillia						1	3	1		1
Freycinetia										7
Pisonia comp.										
Flacourtiaceae undet.										
Apiaceae										
Pittosporum comp.										
Polyscial comp.					1					2
Clematis										
Rubus comp.	1									
Streblus comp.		1								
Melochia comp.					1			1		
Solanaceae								1		
Schefflera comp.								1		4
Cyperaceae 1	4	11		15	1				2	
Cyperaceae 2			4			1				
Cyperaceae 3										
Eleocharis comp.	60	1		279		9	4		3	2
Lepironia comp.			2							
Haloragis sim.										
Potamogeton comp.										
Anthoceros									1	4
Blechnum comp.	10	2	1	7	6	10	8	18	12	8
Cyatheaceae	4		1	12	46	29	49	54	27	34
Dicksonia						2				
Dicranopteris	5	2	6	28	39	20	9	8	3	1
Hymenophyllum			1				1	2	3	
Lygodium	1	2		15	1	17	9	2	1	3
Lycopodium	13	4	1	4	12	4			4	2
Polypodium	1	1		2	3	3	1	15	12	17
Pteridium	2	1			2	2			2	1
Stenochlaena comp.										
Monolete A		1	1	8	12	10	6	10	19	13
Monolete B	3	2		18		2	7		2	

B.5: Wainisavulevu Creek Pollen Counts

Taxa	Sample Depths (cm)													
	490	500	520	530	550	560	570	580	590	600	610	630	640	650
Acalypha	6	3		3	1		3		2	1			3	
Acronychia	1													
Agathis					2						1	1		
Aleurites												1		
Alphitonia	1				1									
Apocynaceae							1	3	5					
Araliaceae undet.		5		2							4		9	3
Ardisia	5							2	2	2				
Arecaceae	12	3	3	8	9	10	33	22	29	28	24	5	5	4
Ascarina	2	11	10	8	10	11	1	1	6	4	18	7	8	16
Baccaurea		1	2											
Balanops	12	39	25	10	21	13	7	10	6	10	3	20	5	13
Bischofia		1	2		1					1			1	1
Calophyllum	5	1		6	5	2	2			4	7	3		2
Calycosia				1	1			1	2			2		
Casuarina		1			1		1		2			1	2	
Celtis comp.									2		2	4		
Claoxylon					1	2								
Clematis											1			
Commersonia				1				1				2		
Collospermum comp.											1			
Coprosma	10	42	5	6	6	11	4	4	3	9	6	7	13	11
Cunoniaceae C2	4	1	4	4	5	4	6	5	6	2		6	4	3
Cunoniaceae C3	9	7	4	4	2	2	2	2	2	2	5	2	3	9
Cupaniopsis						1								
Dacrycarpus								3		1				1
Dacrydium	32	10	19	56	46	41	26	15	15	9	30	41	54	48
Dillenia	2	3	2	1	1		7	1		2		2	1	5
Dodonea			1		1	1								
Dysoxylum	4			2						1		2	1	3
Ebenaceae										1				
Elaeocarpus	7	3	6	6	3	3	3	3	3	11	1	9	6	3
Elattostachys							1							
Embelia	3	2	6	3	3	7	6	5	4	4			1	
Endospermum	1					2								
Euodia		2		1					1			1		1
Exocarpus								2						
Freycinetia	2			1				6	6	5	1		1	
Geniostoma	2	2	2	1	3	1				1	1		3	
Guioa comp.		1						1	1	2		2		
Homalium		1				3		2	2			1		1
Leea comp.	4		1			2						2	1	
Leguminosae		5	5	2		5	5	3	7	7	3	1		6
Liliaceae	1													
Linociera														
Macaranga		2	1		2	1	5	5	1	1	3		3	2
Maesa		2	1		3	7	2	5		2	1	2	4	1
Mallotus			1	1							1	1	1	1
Melastomataceae			3				2	2	1		1		2	2
Meliaceae undet.	1													
Melicope					2		1	1	3		2		1	2

Wainisavulevu Creek cont'd

Taxa	Sample Depths (cm)													
	490	500	520	530	550	560	570	580	590	600	610	630	640	650
Myristica														2
Metrosideros			6									3		
Myrtaceae 1	1		8	3	6	9	2	4	6	5	10	9	7	2
Myrtaceae 2	7	3	22	12	8	9	14	7	8	14	7	10	9	11
Myrtaceae 3						1			4	4		1		
Neonauclea	1	1	2						1			3		1
Neubergia														
Omalanthus					1	1						1		
Ophiorrhiza	1	1	2		2		1					1		2
Palaquium							1		4	1				
Pandanus								1			2			
Paphia comp.	2		2	2		4	1			1	2		1	3
Parinari comp.	5			2		1	2			1	1			1
Pisonia comp.		2												
Pittosporum											2			
Plerandra	2	9	6	3		2	4	4	4	8	3	6	5	2
Poaceae	1	1	1		5	2	2	7	3	1	4	1	1	2
Podocarpus	18	6	12	22	15	17	23	25	29	28	20	3	19	2
Polyalthia comp.				1										
Polyscias comp.	2		2	1			2	3	5	1	4	5		2
Psychotria								1						2
Quintinia comp.	3	1	6	2	6	6	9	11	11	3		5	2	1
Rapanea	8	4		3	2	1	4	3	1	1	5		2	2
Rhamnaceae undet.	4							2			1			
Rosaceae	1										2			
Rubiaceae undet.	1						1				1			
Rubus comp.		1			1									
Rutaceae undet.						1								
Sapindaceae undet.	1	1												
Saurauia	2			2										
Scaevola		1										1		
Schefflera				3										
Solanaceae		1	3		1	1	1		2					1
Symplocos	6	13	17	13	8	15	12	18	6	10	11	11	16	14
Tapeinospermum			2											
Trema comp.		2												
Turrillia			2	4	4	2		3	3	2	2	7	3	2
Urticaceae 1	4		2	2							1	3		2
Urticaceae 2	2	2				2	3	5	3	3	5		1	3
Cyperaceae undet.		1												
Eleocharis comp.						1					3	1		
Blechnum comp.	2						5		1					
Cyatheaceae	66	19	56	110	67	34	66	40	46	52	62	28	64	70
Dicranopteris	1	1		3	3	4		1	4	1	3		3	9
Hymenophyllum	1		1	5		1	1	4	5	4	3			
Lycopodium	6		2	3	3	3		1	1	4	4	1	3	5
Polypodium	7	8	4	3	5		4	2	2	3	6	7	8	3
Pteridium comp.	9		3	2	2							11	5	7
Trilete undet.	1	2	3	2	3	4	3	3	3	5	5	3	2	9
Monolete undet.	35	33	23	31	21	25	29	17	17	20	38	43	46	38
Dicksonia comp.				1									2	

B.6: Bonatoa Bog Pollen Counts

Taxa	Sample Depths (cm)																				
	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	460	380	400
Acalypha		4	1		2		6	6					3	1	1	2	4			2	1
Agathis												1									
Alphitonia	1						1											2			
Annonaceae						2															
Antirrhoea			1	1						2	7										
Apocynaceae												2			1				2	2	1
Arecaceae	12	6	4	6	6	6	12	10	9	12	7	8	7	14	24	8	22	8	22	16	4
Arytera													2								
Asteraceae	2	2	2																	1	
Baccaurea						1					2			4				1		6	3
Bischofia	2	2	1	1	2		8	14	1	4	3	4	4	4	3	8	4	6	1	6	
Calophyllum		1		1				1						1		2	10	6	12	19	2
Calycosia												1							1		2
Casuarinaceae	1				1		1	6							1		2	2		1	2
Celtis comp.	14	14	6	1	6	12	24	26	5	5	6	5	7	5	3	6	1		6	2	2
Commersonia																	1	1			
Cupaniopsis		1																			
Dacrydium							1	1						2			1		1		3
Dillenia	2			1			1					1	1	2	1	2	1	6	6	2	4
Dolicholobium							1				1										
Dysoxylum					1									1				2			1
Elaeocarpus												1							2		
Elattostachys					1						1	4			6		1				
Embelia		1									1		1							2	3
Endospermum						1		6	1			1	1		1	4	1	2	4	2	2
Euodia												1							1		
Euphorbiaceae undet.				1													2	4			
Exocarpus	1																1				
Fagraea										1	3	1		2						2	
Freycinetia															1	2					
Geniostoma					1													1	1		
Glochidion								2		1											
Guioa						1															
Heritiera													2	1			1				
Homalium	1			1		1	2	1		1	1	3	1		1	4		2	4	2	
Leea																		2		2	1
Leguminosae	1	1		1			1					1	1	2				2	1	2	1
Liliaceae																					2
Limnanthemum																					4

Bonatoa Bog Pollen Counts cont'd

Taxa	Sample Depths (cm)																				
	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
Macaranga	6	6	8	1	1	4	2	4		1			3	3		6	8	10	16		8
Maesa			1										1							2	6
Mallotus														1				1		2	1
Malvaceae												1									
Melastomataceae	4	2			2									1	2		4	6	1	2	1
Melicope													1			1		2			1
Melochia comp.						1															
Myristica								1			3	7	4	3	2	2					2
Myrtaceae	4	1												1		4	10	12	16	14	7
Neonauclea							1	1			1		1				2	8	2	2	2
Omalanthus	6	2	6	1	2	2	8	14	2	1	1	1	1			1	6		6	1	3
Ophiorrhiza	1				1		2				2								1		3
Palaquium				1											1	6	6	1	1	1	2
Parinari																		2	1	6	1
Pemphis comp.														1							
Piper				1																	
Pisonia																			1	4	
Pittosporum													1				1				
Plerandra	2	1	1															6	4	4	4
Podocarpus			1	1									1		1	1	1	4	6	6	2
Polyscias													1								
Psychotria			1		1						1				1	1	1				1
Quintinia comp.																	1				
Rapanea							1	2	1	1	1	1				1		1	1	6	2
Rhamnaceae undet.	1							1				1	2		1	1					
Rosaceae		1																			
Rubiaceae undet																				1	1
Rubus comp.			2		1		1				1					2			2	2	
Rutaceae																			1	2	
Scaevola						1		1								1	4	4	4	6	1
Schefflera			1					2									1			1	
Solanaceae		1				1							1			1			2	2	3
Streblus comp.					4								4	4	3						
Symplocos								1									1				2
Tapeinospermum										1		1					1				
Trema comp.	1	8	1	2	4		8	2		2		1	2		1		2				
Turrillia			1																1		2
Urticaceae	14	8	16	8	8	10	6	6	1	4		6	6	5	10	10	14	6	2		2
Poaceae	6	6	18	34	34	49	94	78	170	140	135	98	114	108	83	46	14	1	4	1	1

Bonatoa Bog Pollen Counts cont'd

Taxa	Sample Depths (cm)																				
	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
Metroxylon vitiense												7	7	29	44	56	50	70	60	34	108
Pandanus	110	128	124	132	118	110	14	6	2	4	6	11	10	1	3	10	6	2			2
Canthium sim.								1	9	20	24	20	9	6	1						
Cyperaceae	44	18	18	42	1	18		6	4	11	35	44	44	24	35	4		1	2	1	1
Blechnum comp.	8	4	18	39	84	288	1612	2132	334	396	169	114	98	88	114	34	26	12	26	24	7
Cyatheaceae	38	20	18	18	20	66	82	46	3	4	8	18	29	33	22	46	34	26	26	24	24
Dicranopteris	12	6	6	2	2	6	4	6	2			3	1		3	10	8	12	8	14	4
Hymenophyllum																1		1			2
Lycopodium	8	4	6	6	6	20	629	120	5	6	2	6	6	1	5	2			1	1	2
Lygodium	1	1						1	6	1		6	7	8	10	16	4	2	10	14	10
Polypodium	14	14	12	2	4	14	14	6				3	3	10	12	30	10	18	18	18	7
Pteridium comp.	950	948	864	242	164	260	54					10	1	1		1			4		
Sphaerostephanos	1	1	1	4	10	14	180	60	4	9	14	14	12	13	7	2	1	1			
Monolete A	210	204	276	180	1136	1224	1604	1450	7	23	6	30	13	8	1	10	6	4	12	10	4
Monolete B				1		1	1	1		1	10	36	15	7	5	1	2	1	2		2

B.7: Raralevu Pollen Counts

Taxa	Sample Depths (cm) 20	 30	 40	 50	 60	 70
Acalypha	2	4	7	9	2	3
Alphitonia	1					
Apocynaceae	1	1				
Arecaceae	6	9	2	1	4	6
Arytera			1		1	1
Ascarina		1		1		
Asteraceae		2		1		
Baccaurea			1	4	3	3
Bischofia	21	9	10	25	5	10
Calophyllum			7	6	9	14
Calycosia	1	1				
Casuarinaceae	1	1	1	1	1	2
Celtis comp.	9	5	5	11	2	2
Commersonia			1	1	5	6
Dacrydium				1		
Dillenia				1		
Dolicholobium				1		
Embelia				1		
Elaeocarpus		1	1	1		
Euodia					2	3
Geniostoma		2				
Hedycarya	1					
Leguminosae				2	2	2
Homalium	6	4	1	1		
Macaranga	5	4	7	10	7	7
Maesa		1			1	2
Mallotus				1		2
Melastomataceae		2			5	6
Myrtaceae	3		1			
Neonauclea			1			
Omalanthus	4	2	3	3	1	1
Ophiorrhiza	1				1	1
Pittosporum				1	2	2
Plerandra					2	3
Poaceae	119	107	55	29	52	35
Podocarpus				1	4	4
Polygonum			1			
Rapanea			2			
Rhamnaceae					5	4
Scaevola					1	1
Symplocos					1	1
Trema comp.	8	11	7	3		1
Turrillia				4		
Urticaceae 1				4	1	1
Urticaceae 2	6	9	11	6	8	8

Raralevu cont'd

Taxa	Sample Depths (cm)					
	20	30	40	50	60	70
Cyperaceae undet.		18		1	17	16
Eleocharis comp.			15	15	24	20
Haloragis sim.			13	6	13	10
Metroxylon			2	13	10	12
Pandanus	3	27	38	29	29	30
Brugiera				2	4	3
Rhizophora	2	1	6	4		1
Acrostichum	6	8			68	50
Blechnum comp.	336	512	779	1551	25	20
Cyatheaceae	3	6	4	21	71	80
Dicksonia comp.				1		
Dicranopteris	1				5	5
Lygodium	1	1			2	3
Lycopodium	10	26	8	5	2	1
Polypodium	3	6	1	2	2	2
Pteridium				3		
Sphaerostephanos	6	12	77	290	10	10
Monolete A	1		6	9	45	40
Monolete B	418	608	8	22	5	3

B.8: Vunimoli Swamp Pollen Counts

Taxa	Sample Depths (cm) 0	20	40	60	80	100	120	140
Acalypha	5	1	2			1	4	3
Agathis	1							
Alphitonia			1					
Antirrhoea	2					1		
Apocynaceae				1				
Arecaceae	2	5	8	6	10	11	28	3
Ascarina			1				1	
Baccaurea			1					1
Balanops	6	1	3	6	18	55	2	
Bischofia	3	1	3	1		1	1	3
Calophyllum							4	12
Calycosia							5	
Casuarinaceae	10	13	6	15	16	10	39	5
Celtis comp.	11	5	7	1	1			2
Commersonia	1			1		2		2
Cunoniaceae C2	2	1						
Dacrydium				2		1	1	2
Dillenia			5		1		2	1
Dysoxylum			3			1		2
Elaeocarpus	1	4						3
Elattostachys			1	1				
Embelia						2	4	11
Endospermum	2			1	1	3	8	34
Fagraea		3			1	1		
Freycinetia	1	1		3	12	1		1
Geniostoma				1		1	1	2
Hedycarya	1	1				1	2	
Homalium				1	1		1	1
Ilex	1			6	2			
Ixora	1	1		1	1	3	5	1
Leguminosae	2			2			1	8
Liliaceae	1							
Linocieria comp.				3				
Macaranga	7	4	3	2	3	5	9	14
Melastomataceae		1		2	3			1
Melochia		1						
Myrtaceae 1				37	1			1
Myrtaceae 2				41	1	2	2	
Myrtaceae 3				29	3	1	11	1
Cleistocalyx comp.								
Metrosideros comp.								
Psidium comp.	59	31	68					
Neonauclea comp.			2	3	2	3	2	3
Omalanthus	2	6	2					2
Ophiorrhiza							4	3
Palaquium				2	3		1	4
Pemphis comp.			1					

Vunimoli Swamp Pollen Counts cont'd

Taxa	Sample Depths (cm)							
	0	20	40	60	80	100	120	140
Poaceae	5	6	4	2		1	3	
Podocarpus	2			1	1	2	10	10
Rapanea	20	26	48	1		2		
Rhamnaceae undet.						1		1
Rubus comp.				1				3
Rutaceae undet.		1						
Scaevola comp.	14					1	1	3
Solanaceae				1	1			
Streblus comp.			1					
Symplocos	1			1			2	
Trema comp.	6	2	3					
Urticaceae 1	2						1	1
Urticaceae 2	8	2	5		3			6
Wikstroemia					1			
Arecaceae echinate				19	60			
Euphorbiaceae undet.					1			
Clematis comp.							2	
Melicope							1	2
Rubiaceae undet.							1	
Polyscias comp.							1	
Maesa							3	2
Acronychia							1	1
Canthium comp.							1	4
Guioa								1
Planchonella								2
Metroxylon				278	372	486	1754	1922
Pandanus	22	78	23	55	83	84	5	12
Rhizophora		3	2	2	1	2	12	6
Brugiera						1	16	5
Eleocharis comp.	32	2	15	2	9		2	3
Lepironia comp.	4							
Cyperaceae undet.			10				4	
Haloragis sim.							2	
Blechnum	10	3	11	13		2	20	44
Cyatheaceae	58	76	33	5	6	5	3	28
Dicranopteris	2	4				1		1
Hymenophyllum							1	3
Lycopodium	17		1					1
Polypodium	23	3	8	24	11	11	12	156
Pteridium			4	7		3		
Monolete A	40	86	32	7	2	1	4	1
Monolete B							2	
Sphaerostephanos	6	1		12	14	4	16	166
Lygodium				4	34	22	6	20

B.9: Melimeli Swamp Pollen Counts

Taxa	Sample Depths (cm)		
	180	320	460
Arecaceae	6	1	4
Ascarina		1	
Bischofia	10	2	
Calophyllum			1
Casuarina	1		
Dacrydium			3
Dysoxylum			1
Elaeocarpus	1	1	
Elattostachys	1		
Embelia	3		
Freycinetia			2
Homalium	2		
Macaranga	10		1
Metrosideros		1	
Myristica			1
Myrtaceae 1	1		
Myrtaceae 2	4		2
Myrtaceae 3	2		1
Omalanthus	1	1	
Poaceae	4	2	
Podocarpus	2		
Quintinia comp.	1		
Rapanea	1		
Rhamnaceae		1	1
Scaevola			1
Ulmaceae		1	
Urticaceae 1	1	1	
Urticaceae 2	5		
Brugiera	51	9	2
Lumnitzera	4		
Rhizophora		1	4
Pandanus	7		2
Metroxylon	3	3	6
Acrostichum			2
Blechnum comp.	11	2	1
Cyatheaceae	7	1	7
Dicksonia	2	5	1
Lycopodium		1	1
Lygodium	7	3	2
Polypodium	4	5	3
Sphaerostephanos	3		
Monolete A		1	3